Course on Data Analysis and Visualization

Visual Perception

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One Minute Paper

- Used as Feedback from **you** to **me**
- Anonymous
- Take a piece of paper and use for **front** for **positive feedback** and the **back** for **negative feedback**
- Do this at the end of the lecture
- This will be repeated at in January and at the end of the course.

Literature

Information Visualization

C. Ware, Information Visualization: Perception for Design, Morgan Kaufmann Publishers, San Diego, 2000

R. Spence, Information Visualization: Design for Interaction, 2nd edition, Pearson Prentice Hall, Harlow, 2007

C. Chen, Information Visualization: Beyond the Horizon, 2nd edition, Springer, Heidelberg, 2006

E. R. Tufte, Envisioning Information, Graphics Press, Cheshire, 1990

Graph Visualization

G. Battista, P. Eades, R. Tamassia, I. G. Tollis, Graph Drawing: Algorithms for the Visualization of Graphs, Prentice Hall, Upper Saddle River, 1999

L. Krempel, Visualisierung komplexer Str ukturen: Grundlage und Darstellung mehrdimensionaler Netzwerke, Campus, Frankfurt, 2005

Gestalt Psychology

A. Seyler, Wahrnehmen und Falschnehmen: Praxis der Gestaltpsychologie, Anabas, Frankfurt, 2004

W. Metzger, Gesetze des Sehens, Waldemar Kramer Verlag, Frankfurt, 1975

D. Katz, Gestaltpsychologie, Schwabe & Co, Basel, 1969

All material, especially pictures that do not indicate a source (URL), are taken from *C. Ware, Information Visualization: Perception for Design*.

Central Question

What is the optimal *representation of data*, which *humans understand* as good as possible to finally reach an *optimal decision*?

Semiotics

"Semiotics is the science of symbols and signs (processes) in nature and culture. Symbols and signs transfer information in time and space. Without semiotics, cognition, communication, and cultural meaning would not be possible."

Translated from the German source of the DSG – Deutsche Gesellschaft für Semiotik, www.semiose.de

Pioneers: C.S. Peirce, F. de Saussure

Semiotics and Visualization

- **Information visualization** is about **diagrams** and how these enable and support the **understanding of information**
- **Diagrams** are composed by **symbols and signs**
- **The meaning of symbols and signs** emits from **socio-cultural conventions**, which are established in **person-to-person** communication
- **Visual perception** is thereby out of the sight of philosophy and nominalitic irrelevant to understand the code

Nevertheless, visual perception **should be considered in the creation of visual languages to minimize the learning effort** necessary to understand the visual code.

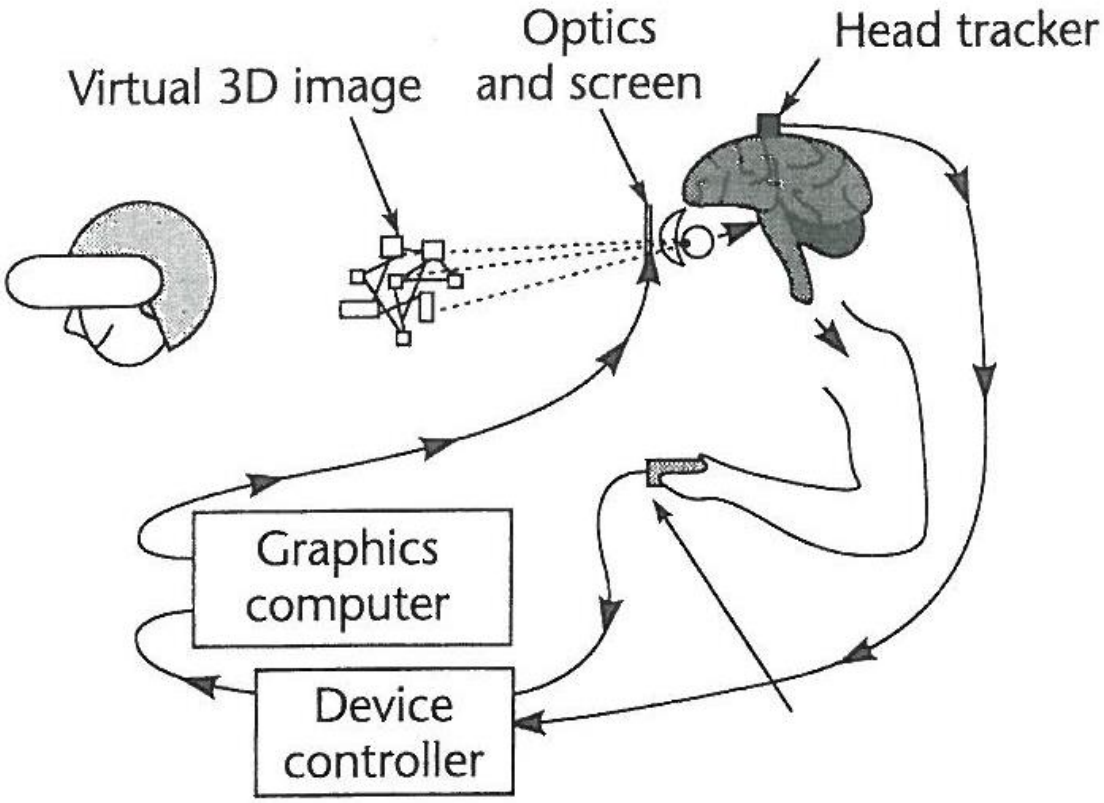
Semiotics and Visualization

Cave Painting

http://creepypasta.wikia.com/wiki/The_Angel_of_Industry, accessed on 2014-10-15

Semiotics and Visualization

VR Diagram



Semiotics and Visualization

Equation

$$X \propto \int_{1}^{\infty} \omega \oint \left\| \frac{\pi \tau_i}{\oint \varphi} \right\|$$

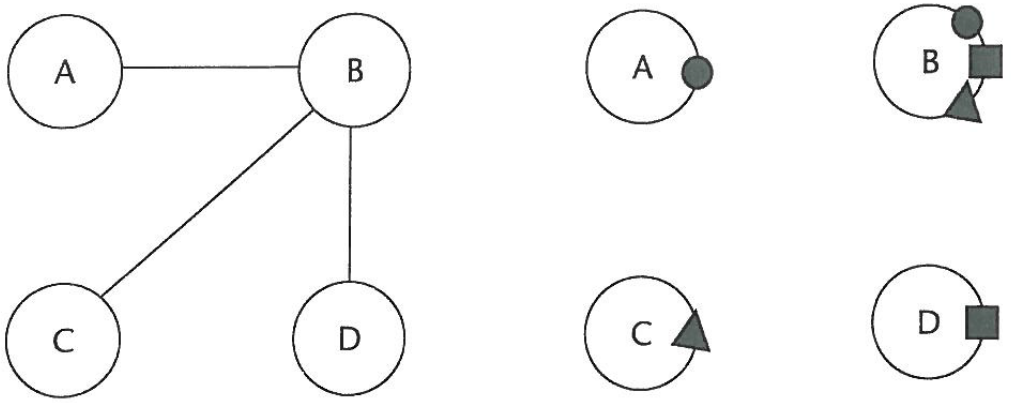
Semiotics and Visualization

Why are pictographic representations simpler to understand than abstract representations, such as mathematical equations?

- Higher degree of experience with pictographic representations
- Represented concepts are better known as those more abstract representations are used

Attempt to Explain

- Pearson et al. (1990) believe that similar sub-processes in the visual perception are triggered if a pictographic representation or the represented object are perceived
- Conventions play a central role in perception, especially if the context of pictographic representation has been removed
- The same data is represented, where the left representation is simpler to understand because the visual cortex contains mechanisms for following continuous lines.



Overview

- **Introduction - DONE**
- Sensory vs. Arbitrary Symbols
- The Human Eye
- Luminance, Contrast, Color
- Gestalt Psychology

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Sensory vs. Arbitrary Symbols

Sensory: Referenced symbols and visualizing processes achieve their meaning through the human perceptual and cognitive system in the brain → **There is no learning necessary**

Arbitrary: Referenced symbols and visualizing processes have to be learned and are thereby independent from the human perceptional system → **Learning is necessary**

Example: The word **DOG** as set of characters or symbols has no reference to the animal, which is meant here

In general: Both, sensory and arbitrary symbols occur as combination

Sensory vs. Arbitrary Symbols

Sensory Symbols

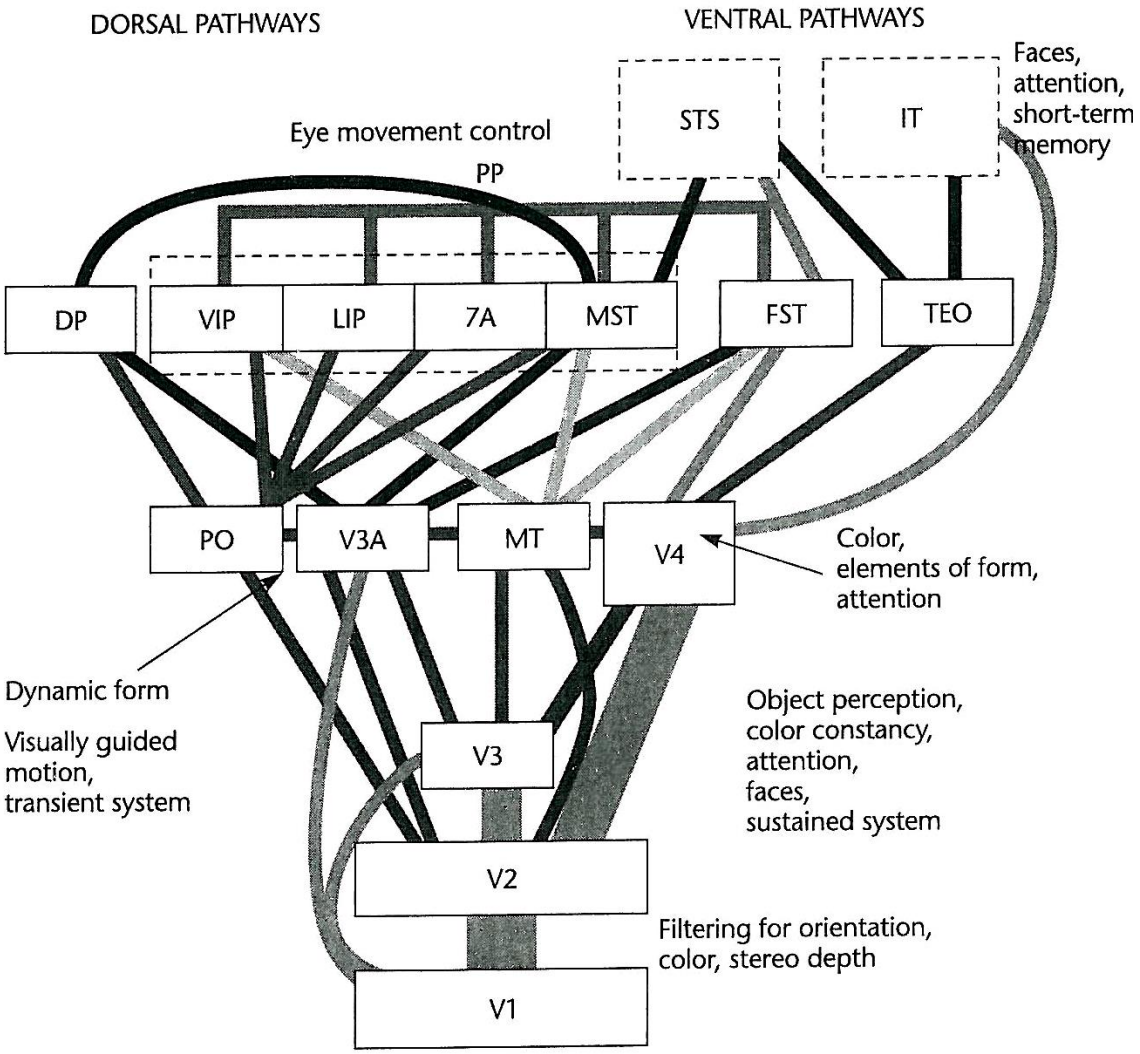
- Effective representation of information because of the early cognitive processing in neuronal processes
- Stability regarding cultural influences

Arbitrary Symbols

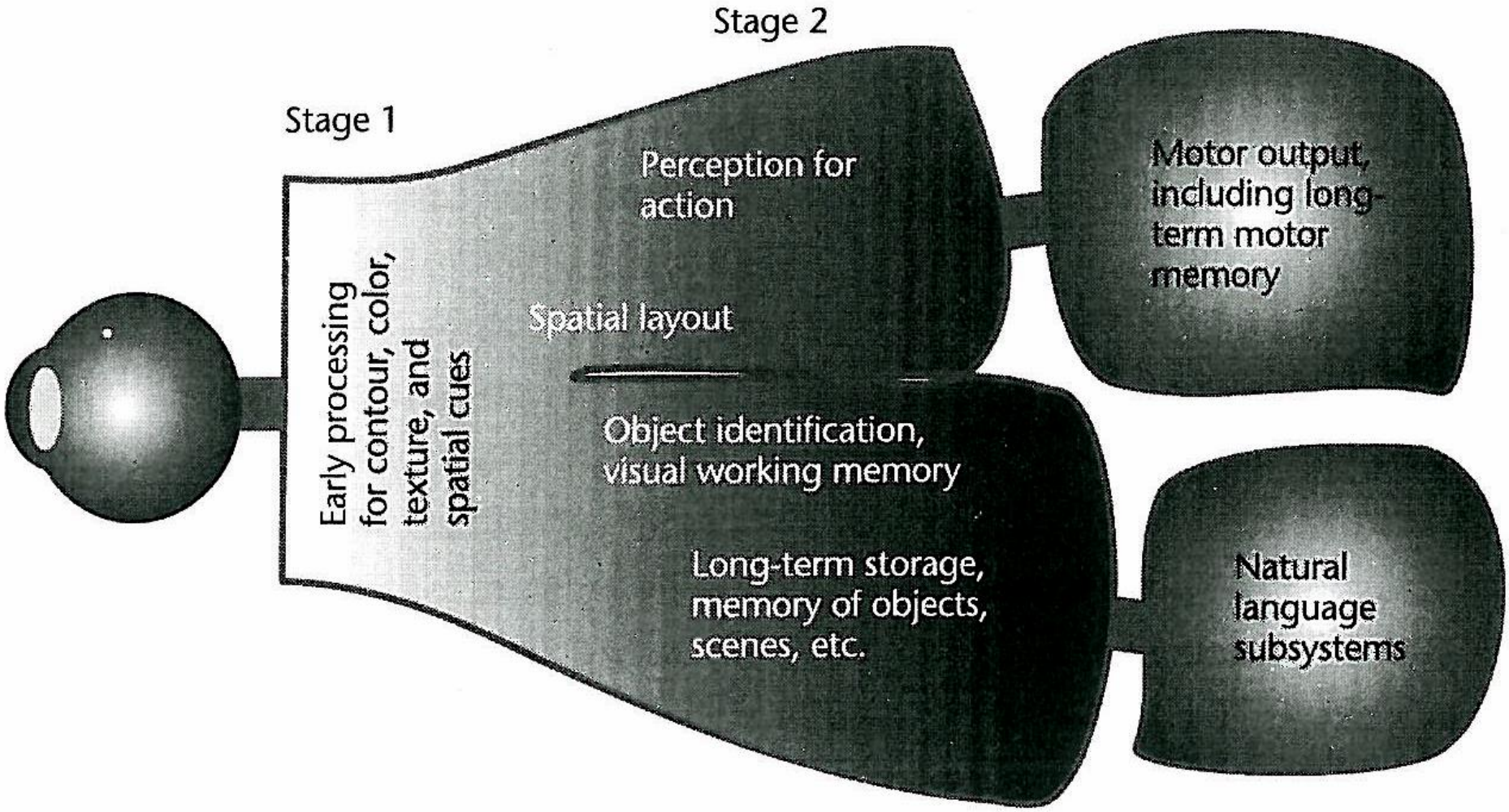
- Direct dependency on cultural influence
- Somehow „programmable“

→ Sensory sensing is more efficient but more static ←

Pathways

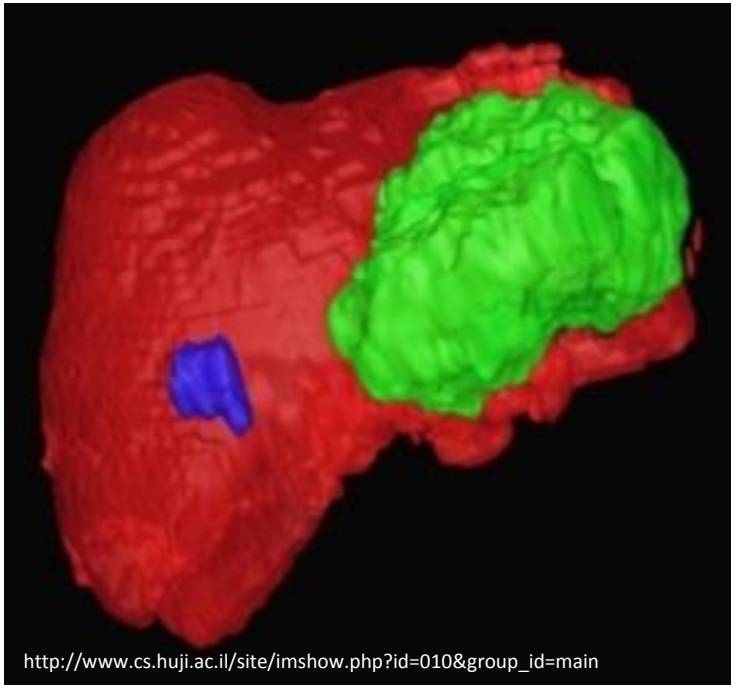

DORSAL PATHWAYS
VENTRAL PATHWAYS
Faces, attention, short-term memory
STS
IT
Eye movement control
PP
DP
VIP
LIP
7A
MST
FST
TEO
PO
V3A
MT
V4
Color, elements of form, attention
Dynamic form
Visually guided motion, transient system
Object perception, color constancy, attention, faces, sustained system
V3
V2
Filtering for orientation, color, stereo depth
V1

General Model of Visual Perception



Understanding without training

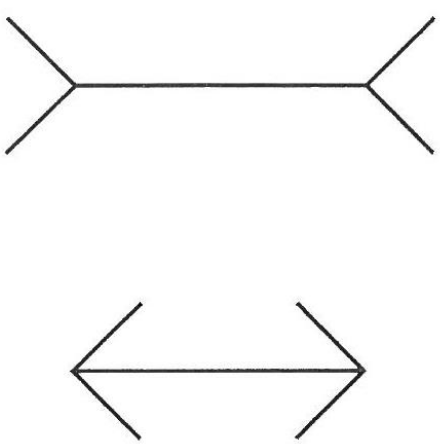
Sensory code is code, which can be understood without additional training

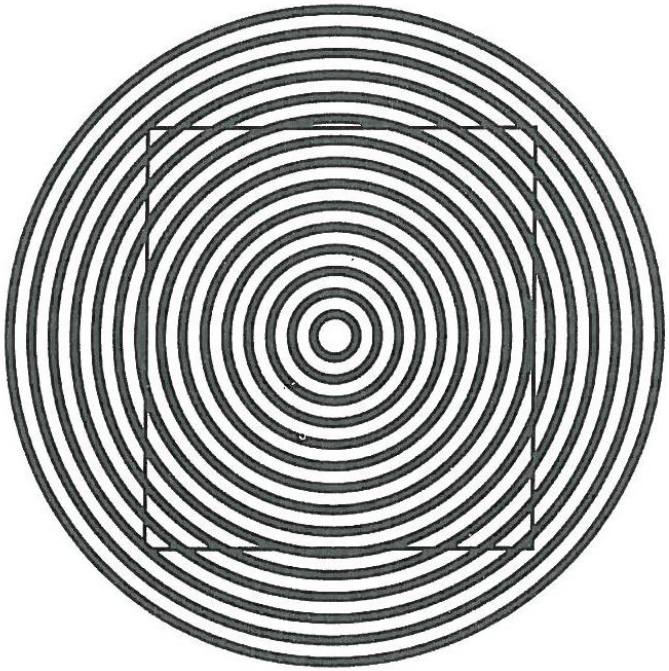


Segmentation of a liver to identify tumors

Resistant to Explanation

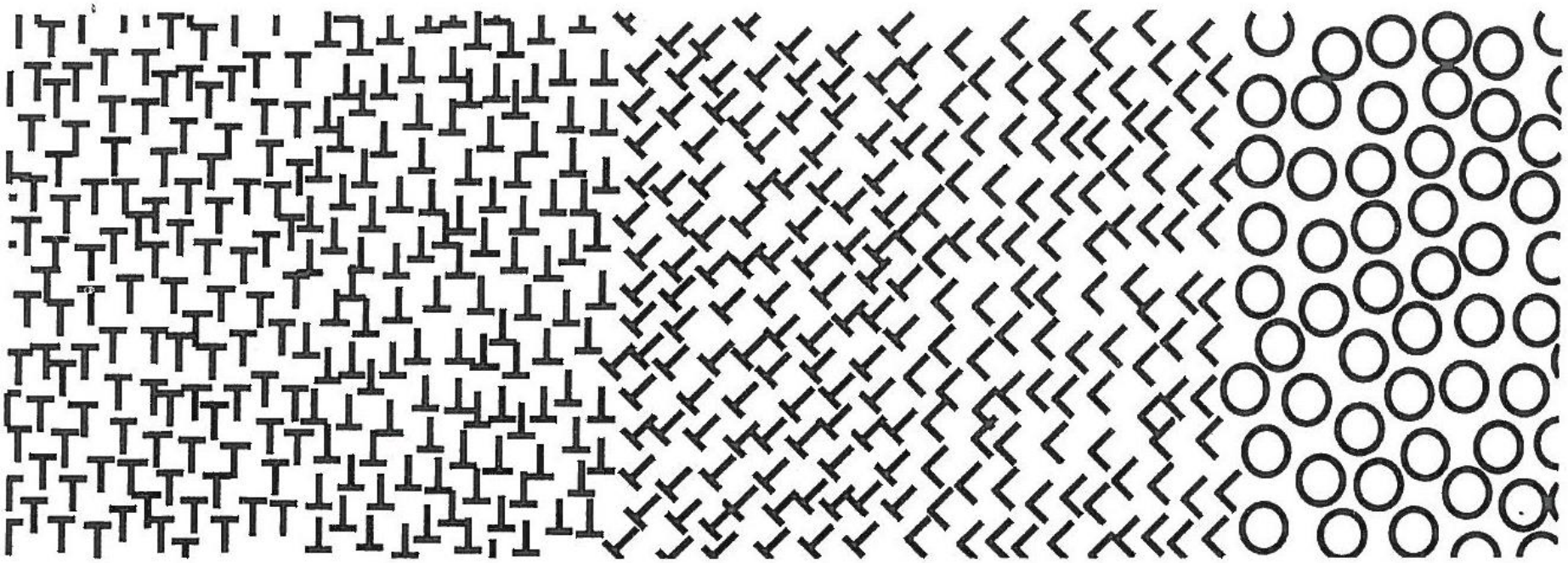
Various sensory phenomena, such as optical illusions are resistant to their explanation





Sensory Directness

Specific types of processing is hard wired and very fast



Cross-Cultural Validity

- Sensory code is valid over cultures and are understood in the same way in front of different cultural backgrounds.
- This assertion looses its validity if the sensory code is overwritten by cultural agreements.

Characteristics of Arbitrary Representations

Hard to Learn

Arbitrary codes and representations are hard to learn, such as reading and writing.

Easy to Forget

Arbitrary information is simple to forget if it is not learned by heart.

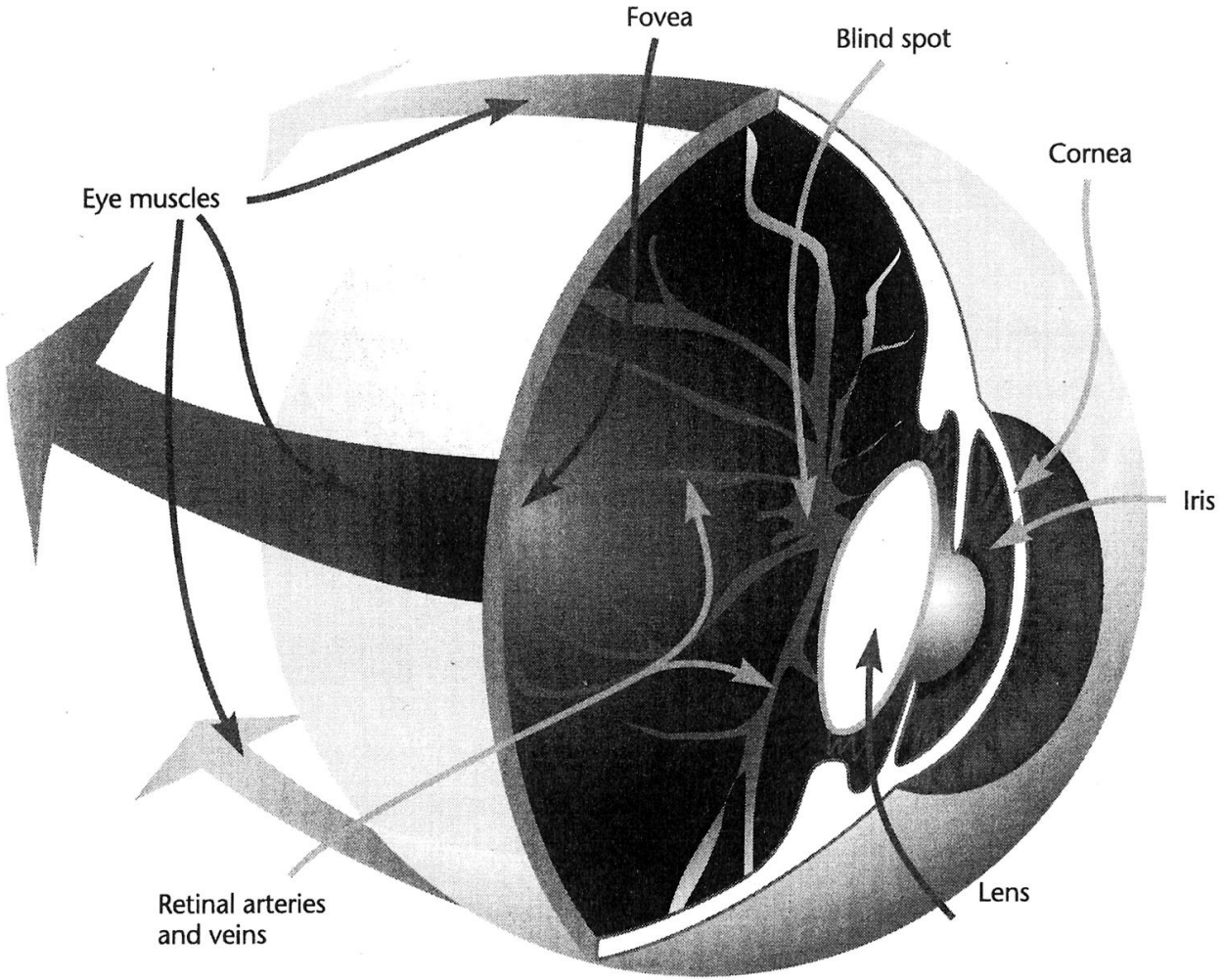
Embedded into Cultural Context

Arbitrary codes and representations depend on culture and applications.

Overview

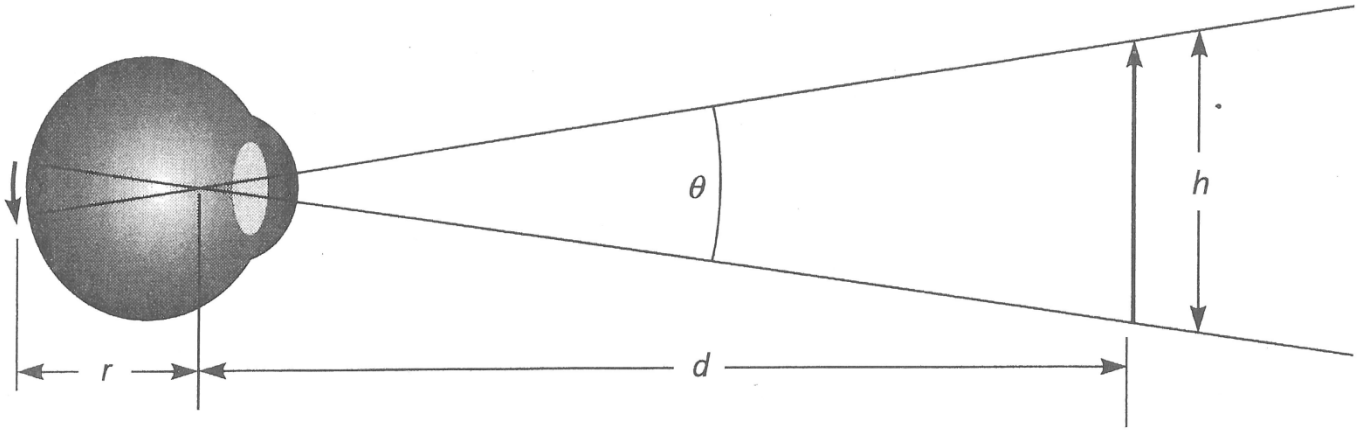
- Introduction
- Sensory vs. Arbitrary Symbols
- **The Human Eye**
- Luminance, Contrast, Color
- Gestalt Psychology

The Human Eye



The Human Eye - Visual Angle

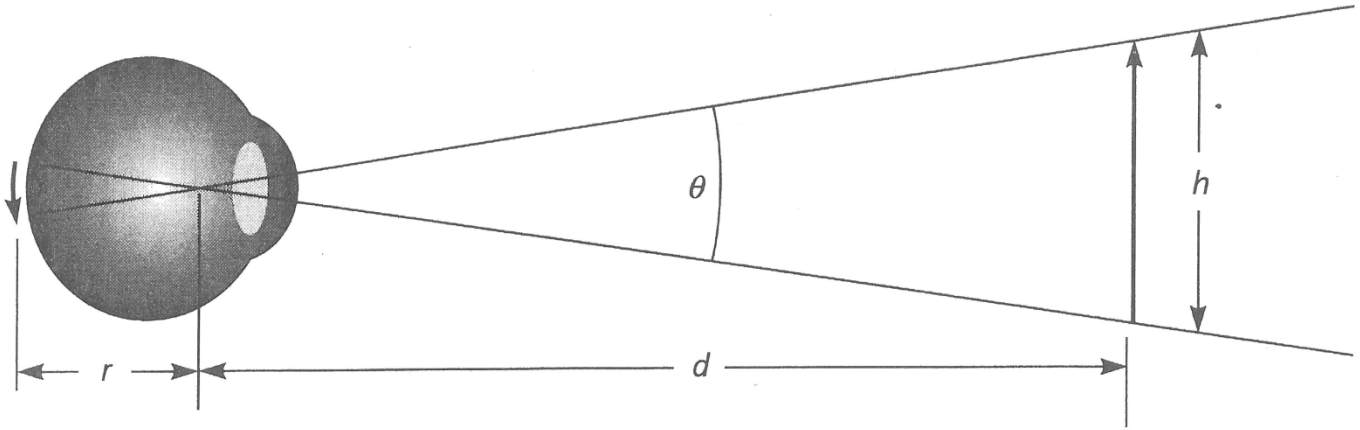
- 1cm object (h) in 57cm distance (d) match 1°



$$\theta = 2 \arctan\left(\frac{h}{2d}\right)$$

The Human Eye - Lens

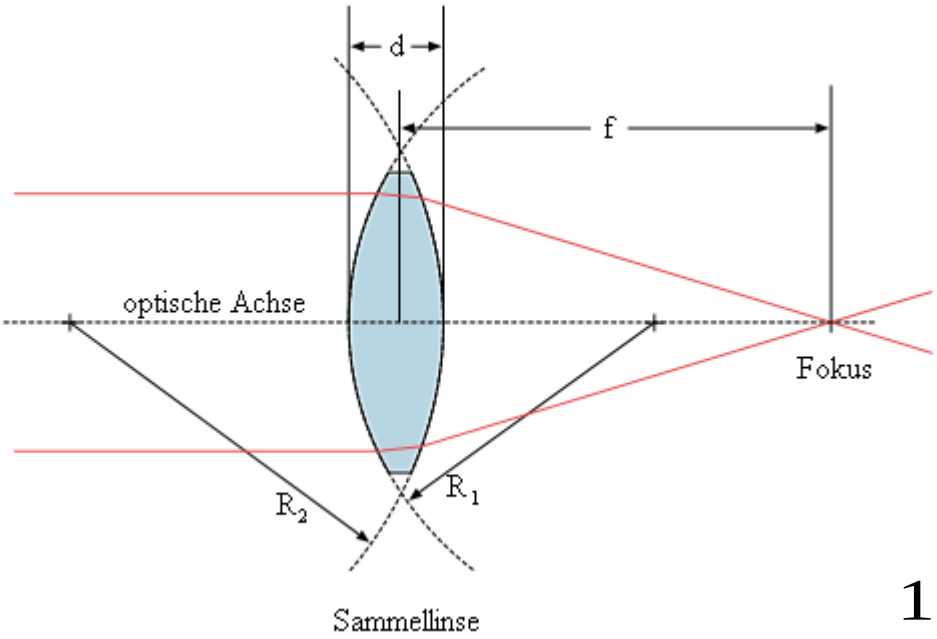
- The lens has the task to focus the (inverse) image on the retina



$$\frac{1}{f} = \frac{1}{d} + \frac{1}{r}$$

- 17mm focal length, 40 to 59 Dioptrin refraction

Excursion: Lensmaker‘s Equation



http://upload.wikimedia.org/wikipedia/commons/9/96/Sammellinse.svg

$$D = \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

D	refraction [Dioptrin]
f	focal Length [m]
R_1, R_2	outside Radius [m]
n	refractive Index

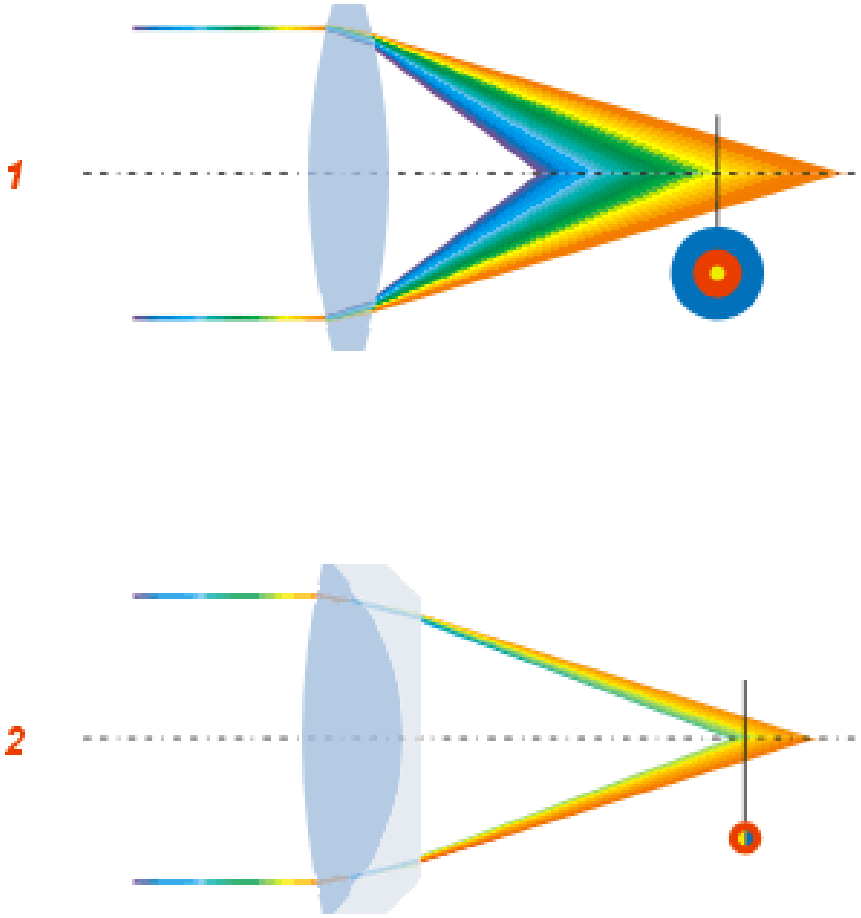
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{d} + \frac{1}{r}$$

The Human Eye – Depth of Field

J. Hancock, Fotografieren, DK, 2008

The Human Eye – Chromatic Aberration

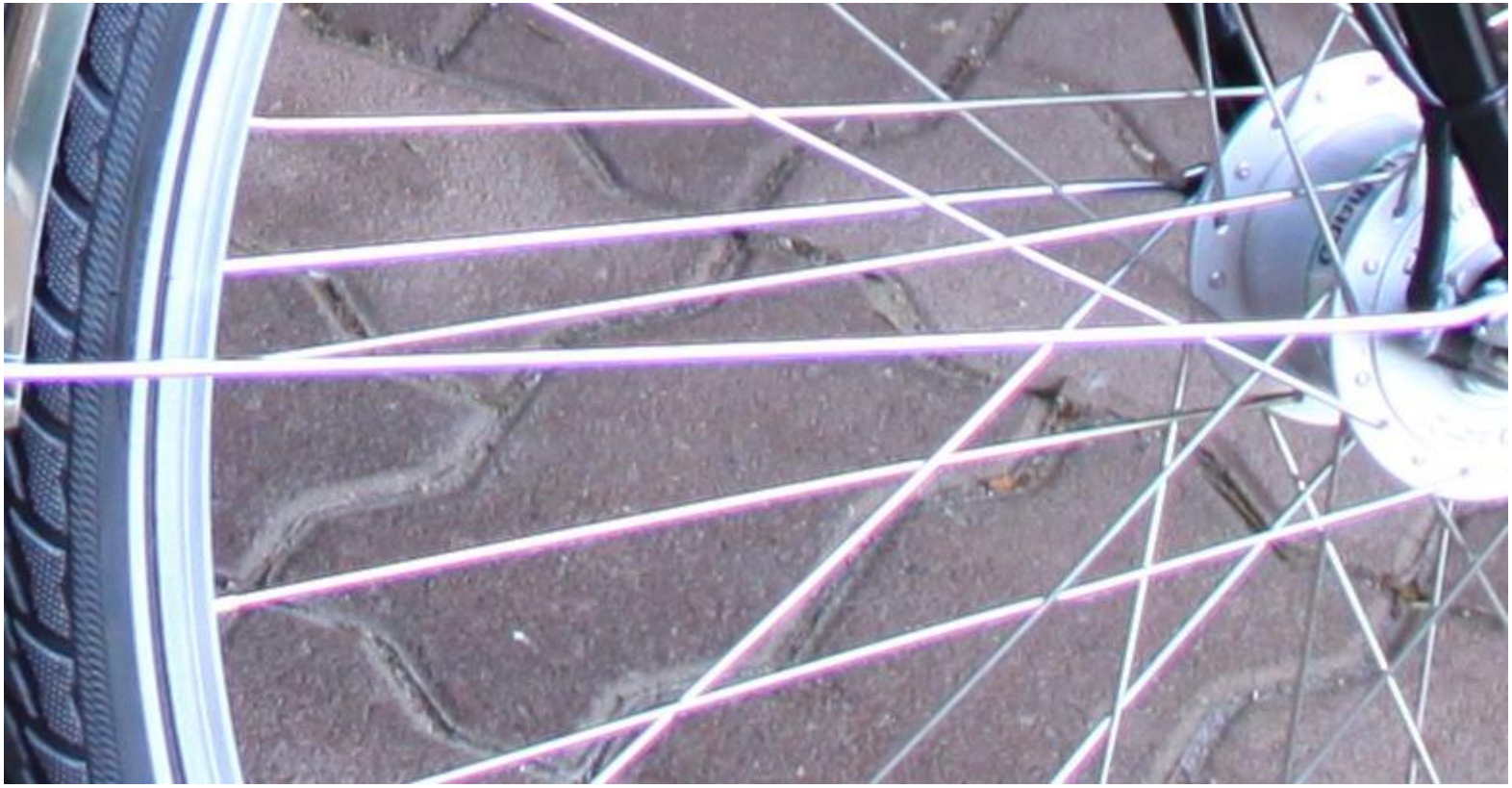
- Appears in optical systems through refraction
- Light is a mixture of different wave lengths, which are refracted in different ways
- A mixture of different lens materials can reduce the effect
- The human eye is NOT corrected



http://olypedia.de/Bild:Lens_chromatic_aberration_Wikimedia.png

The Human Eye – Chromatic Aberration

The Human Eye – Chromatic Aberration

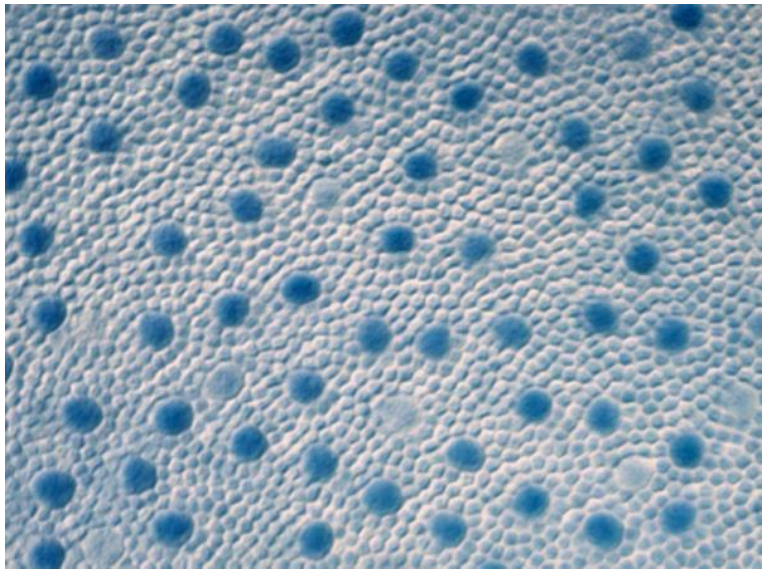


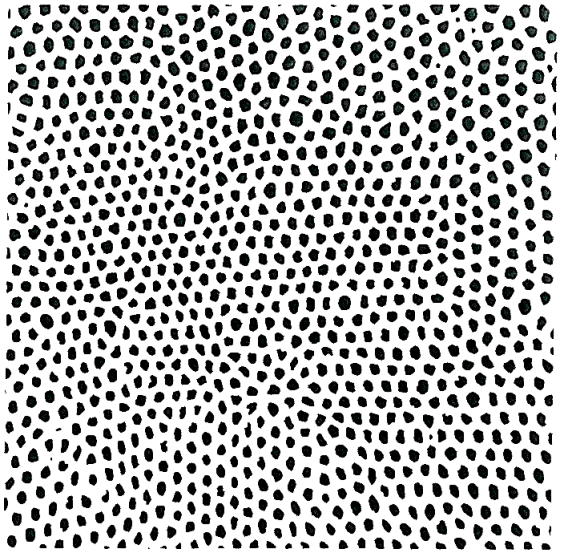
http://www.roesener.homepage.t-online.de/ausschnitt.jpg

The Human Eye – Receptors

- The retina contains mainly two types of receptors
  - Rods (100 million), intensity perception
  - Cones (6 million), perception of colors: **red**, **green**, **blue**

- The sharpest point of the retina is located in the center of the retina (fovea centralis), which solely contains cone cells.



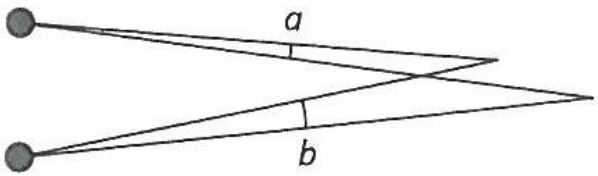


http://bost.ocks.org/mike/algorithms/

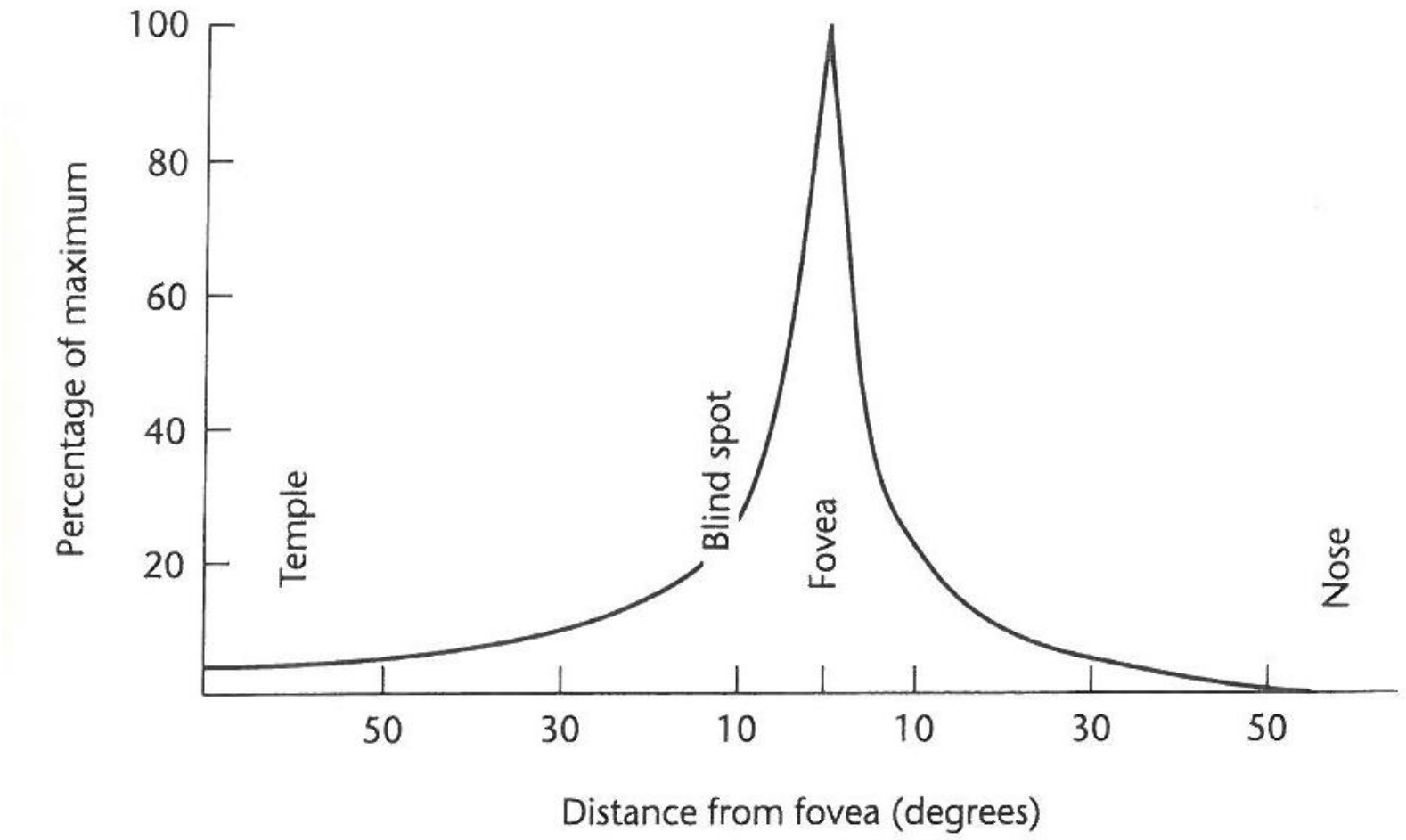
The Human Eye – Visual Acuity

Point acuity (1 minute of arc): The ability to resolve two distinct point targets.	
Grating acuity (1–2 minutes of arc): The ability to distinguish a pattern of bright and dark bars from a uniform gray patch.	
Letter acuity (5 minutes of arc): The ability to resolve letters. The Snellen eye chart is a standard way of measuring this ability. 20/20 vision means that a 5-minute letter target can be seen 90% of the time.	

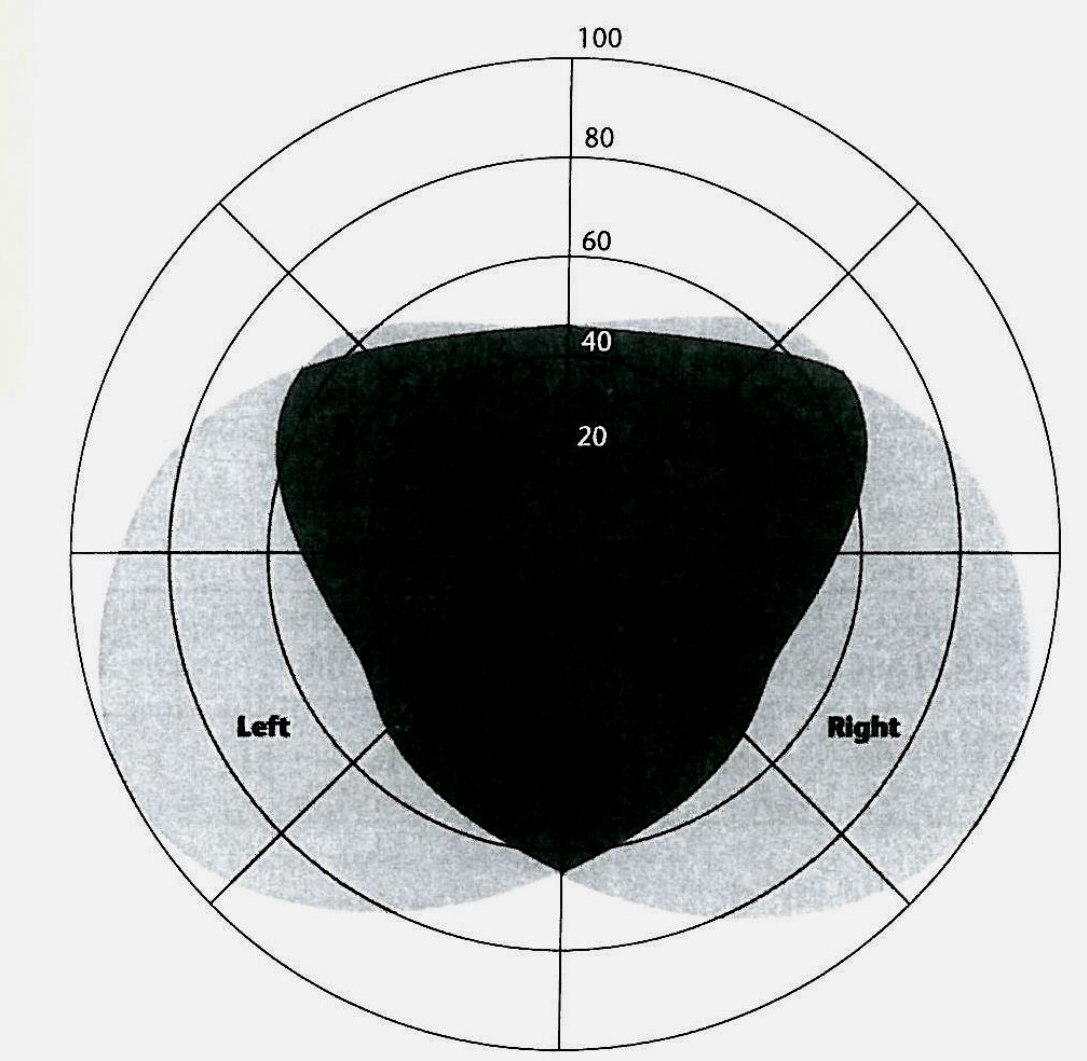
The Human Eye – Visual Acuity

Stereo acuity (10 seconds of arc): The ability to resolve objects in depth. The acuity is measured as the difference between two angles (*a* and *b*) for a just-detectable depth difference.	
Vernier acuity (10 seconds of arc): The ability to see if two line segments are collinear.	

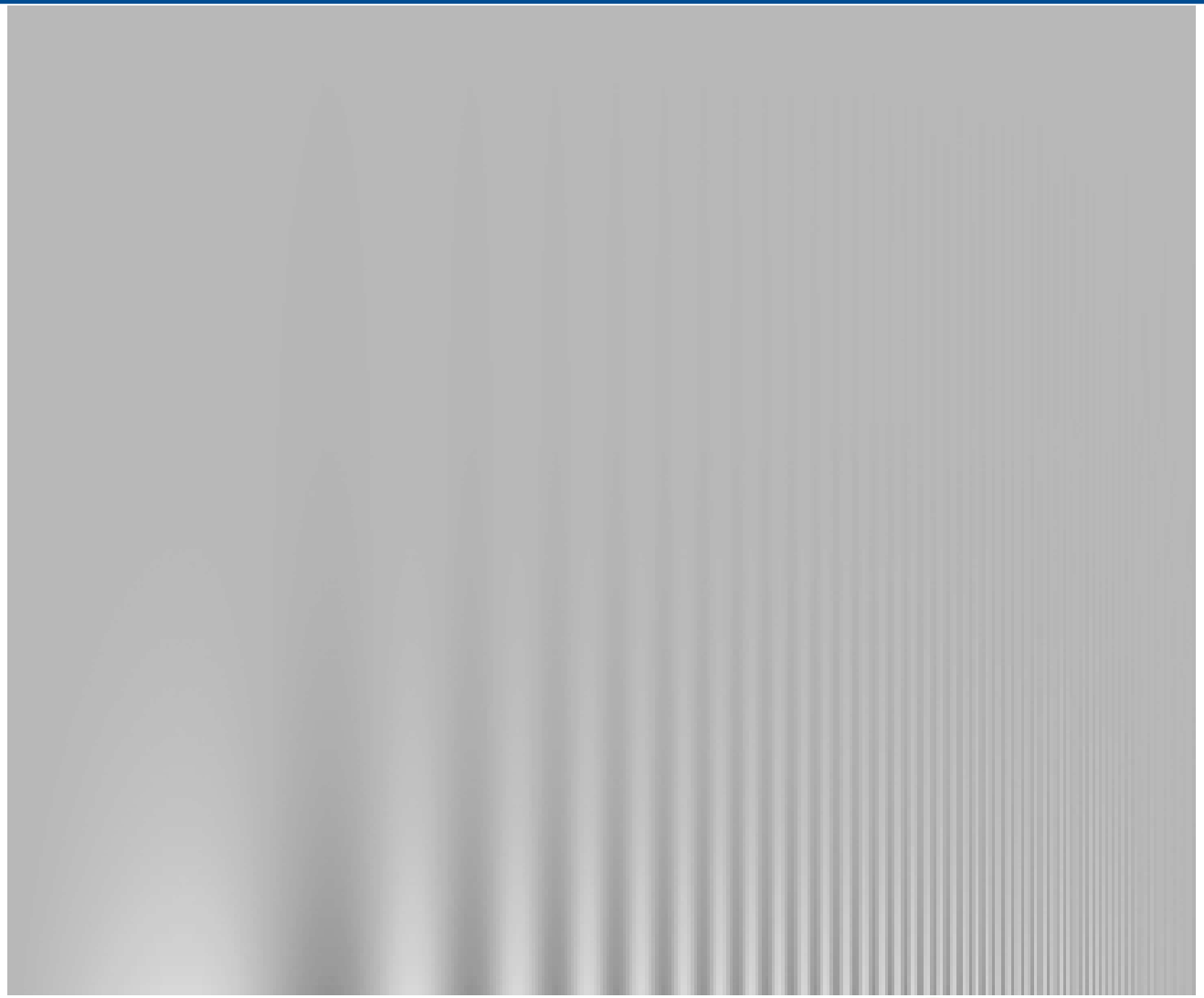
The Human Eye – Visual Acuity



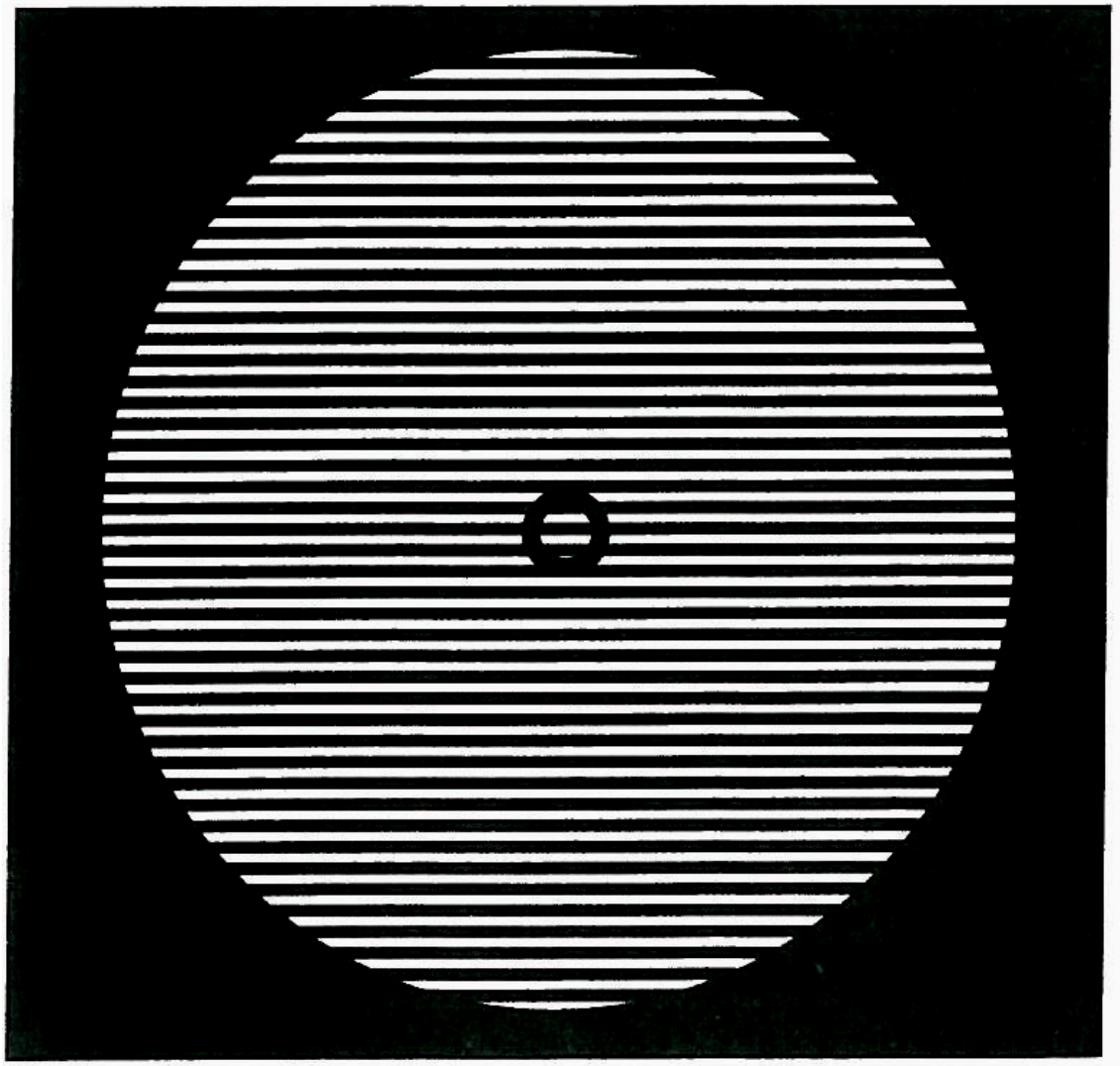
The Human Eye – Visual Field



The Human Eye – Space-Contrast-Sensitivity



The Human Eye – Visual Stress



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- Gestalt Psychology

General Problem

The visual system is based on **relative perception**, NOT an absolute sensing of light.

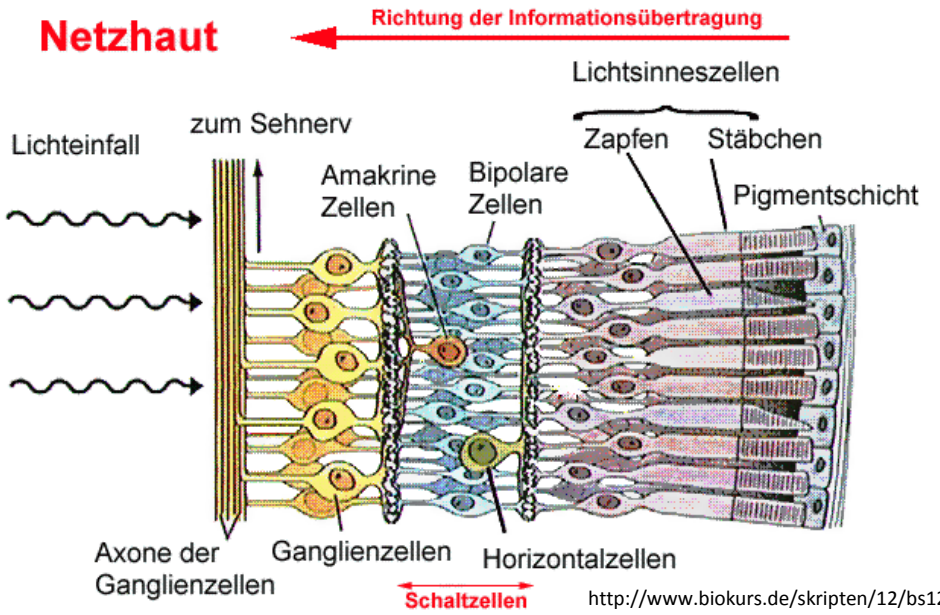
Question: How does a beamer show black (meaning no light) on the wall? Answer: Simply not…

General Problem

No measurement of light, but measurement of **light differences**.

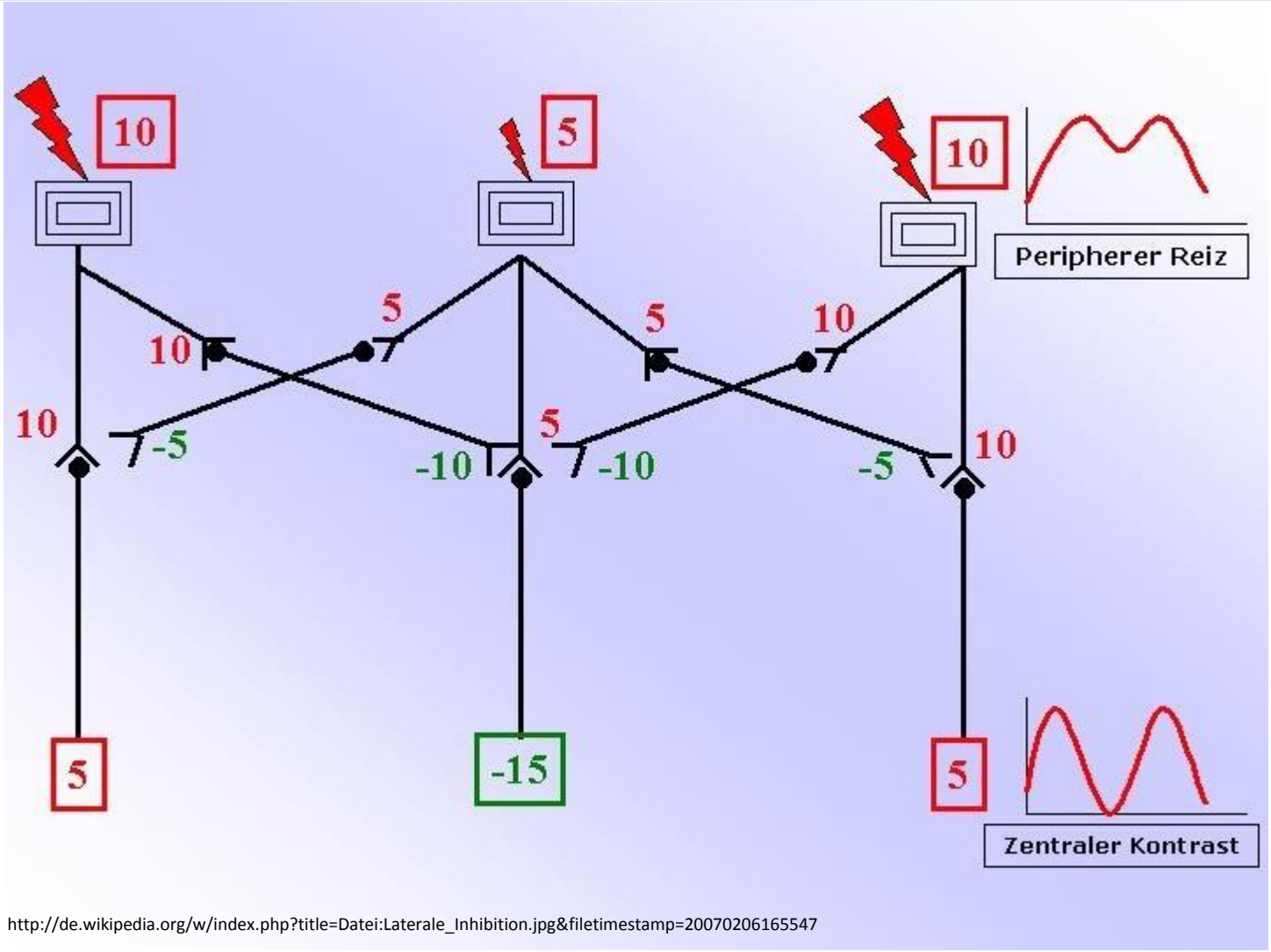
Receptors and Neurons

- The basic principal of neurons is to constantly generate electrical pulses
- Neurons can be stimulated or inhibited by other neurons, which increases or decreases the number of pulses a neuron generates
- Receptor show specific areas that react on specific stimuli – here light
- These stimuli are transferred into electric pulses, which act as stimulation or inhibition



http://www.biokurs.de/skripten/12/bs12-36.htm

Lateral Inhibition



http://de.wikipedia.org/w/index.php?title=Datei:Laterale_Inhibition.jpg&filetimestamp=20070206165547

Activation Model

- Difference of Gaussians model, short DOG

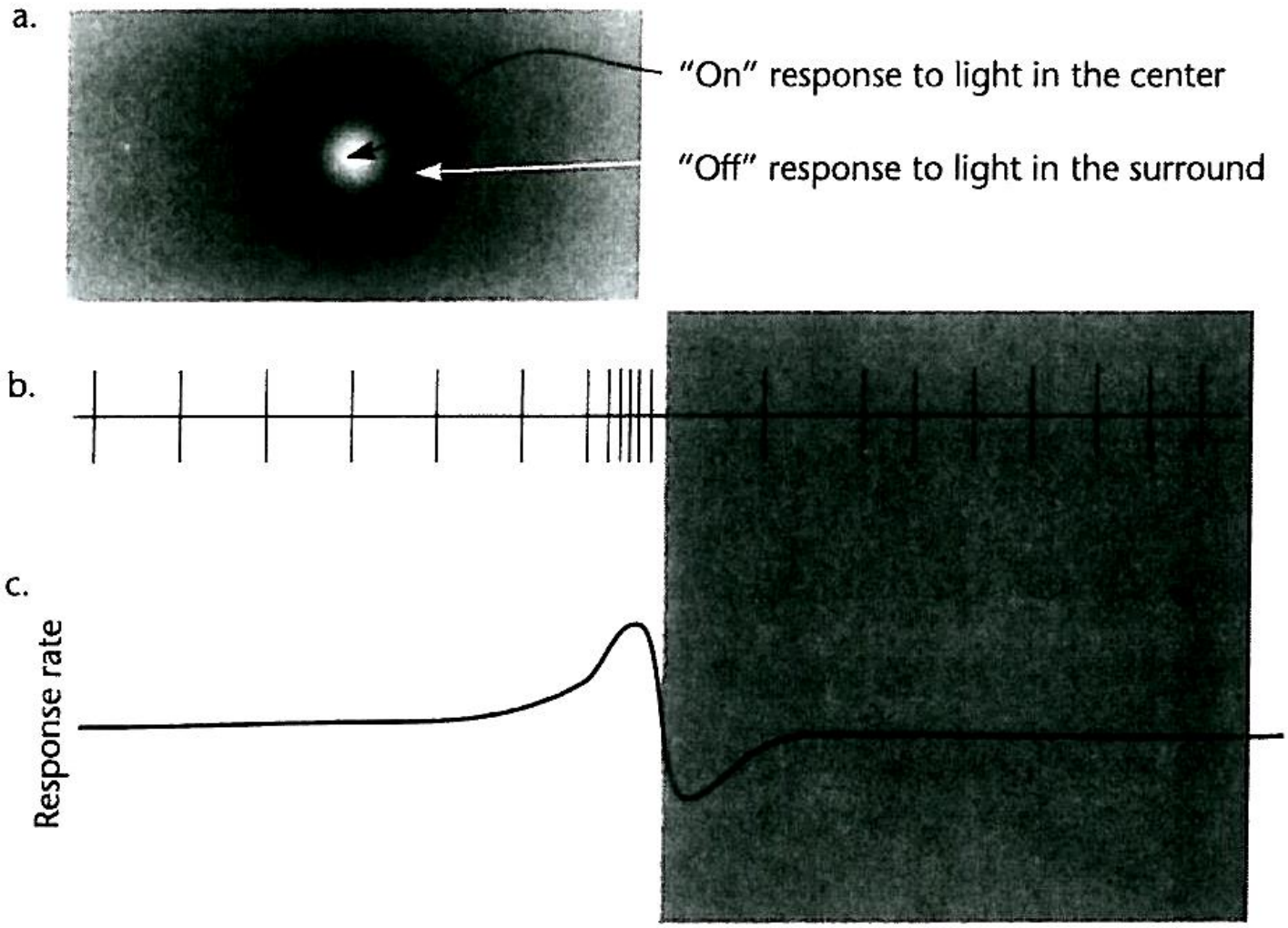
$$f(x) = \alpha_1 e^{-\left(\frac{x}{w_1}\right)^2} - \alpha_2 e^{-\left(\frac{x}{w_2}\right)^2}$$

x Distance to sensitive point

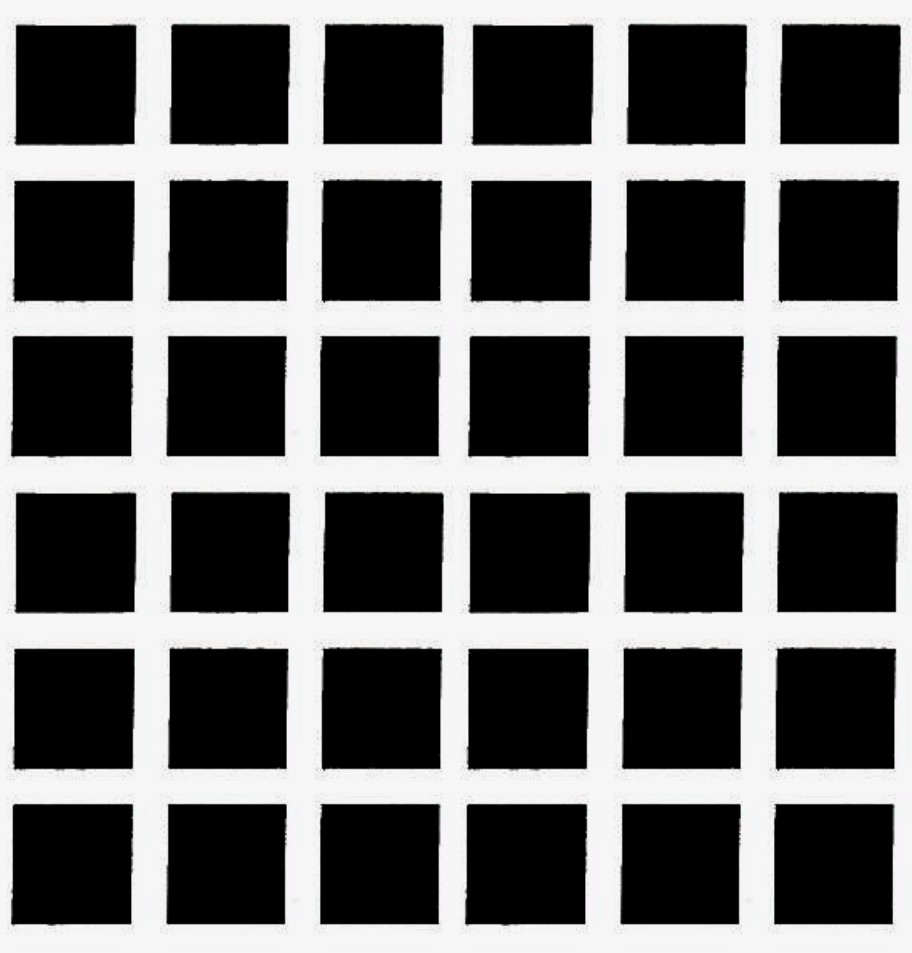
α_1, α_2 Strength of activation or inhibition

w_1, w_2 Width of the active center and width of the surrounding area

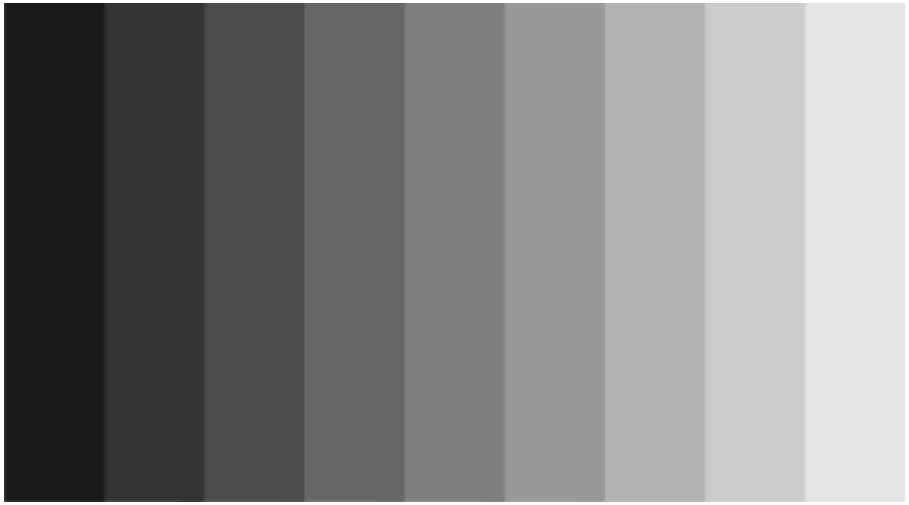
DOG


a.
"On" response to light in the center
"Off" response to light in the surround
b.
c.
Response rate

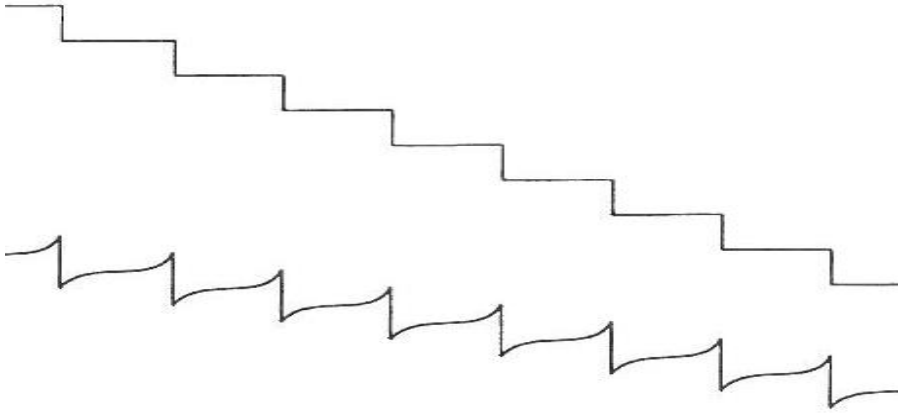
DOG



Cevreull Illusion



http://www.psy.ritsumei.ac.jp/~akitaoka/Chevreulillusion.jpg



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Luminance, Brightness, and Lightness

- **Luminance:** The amount of measured light emitted from any point in space. This is the only term of the three relating to a physically measurable quantity.

- **Brightness:** The perceived amount of light from any point in space. Only self-emitting light sources are considered in this context; brightness of a color is not meant here.

- **Lightness:** The perceived reflection characteristic of a surface. A white surface is maximal light, a black one maximal dark. Shade of a color is also addressed by the term lightness.

Luminance

- Physical dimension, which defines the quantity of light in the visible spectrum
- Luminance is defined as light energy weighted by the spectral sensitivity of the human eye → $V(\lambda)$
- $V(\lambda)$ is defined by the CIE standardization commission

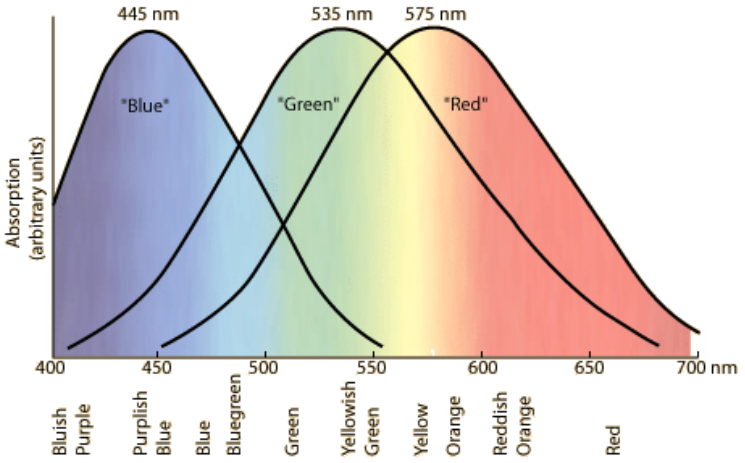
$$L = \int_{400}^{700} V_\lambda E_\lambda \delta\lambda \quad \left[\frac{cd}{m^2}\right]$$

E_λ Light distribution

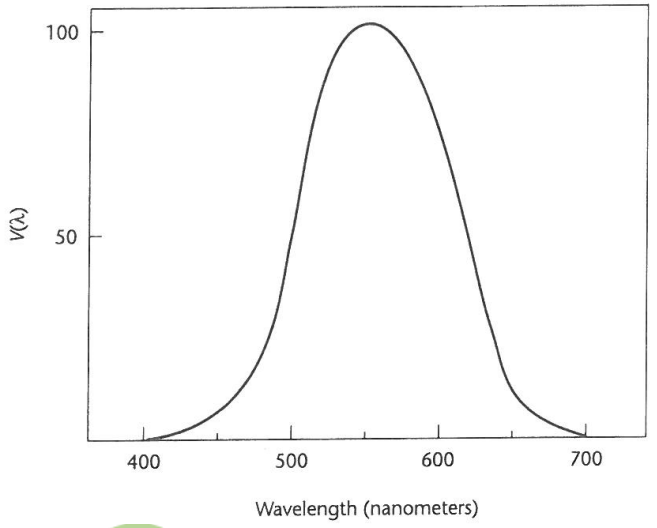
V_λ Wave length dependent sensitivity

λ Wave length

$\left[\frac{cd}{m^2}\right]$ Candela per square meter



http://hyperphysics.phy-astr.gsu.edu/hbase/vision/colcon.html



Brightness

- Brightness defines the perceived amount of light, which is a highly non-linear cognitive magnitude
- Stevens (1961) derived a simple relation between luminance and brightness

$$S = aI^n$$

$$Bri = Lum^n$$

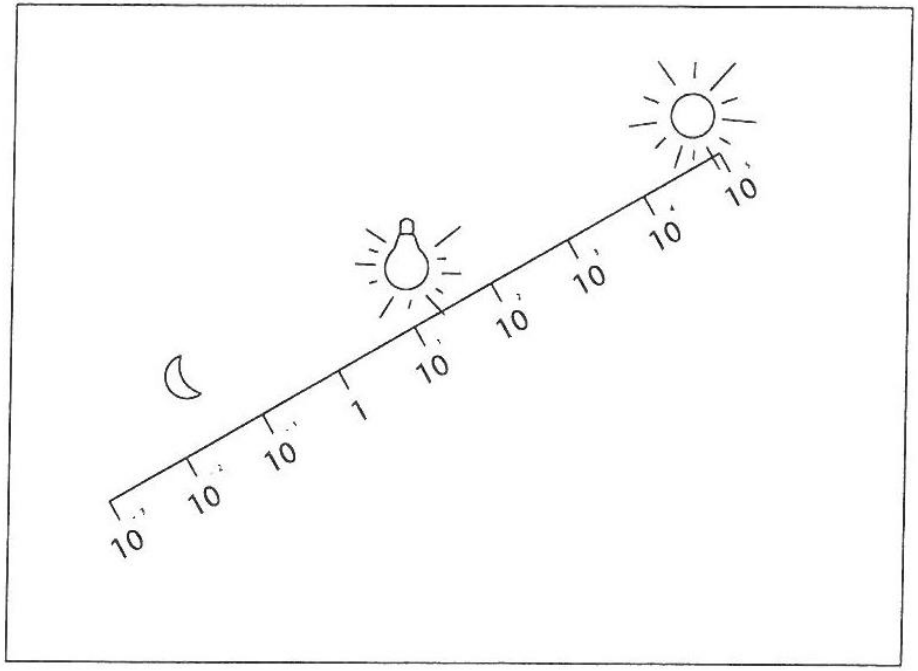
S Perceived Brightness

I Light Intensity

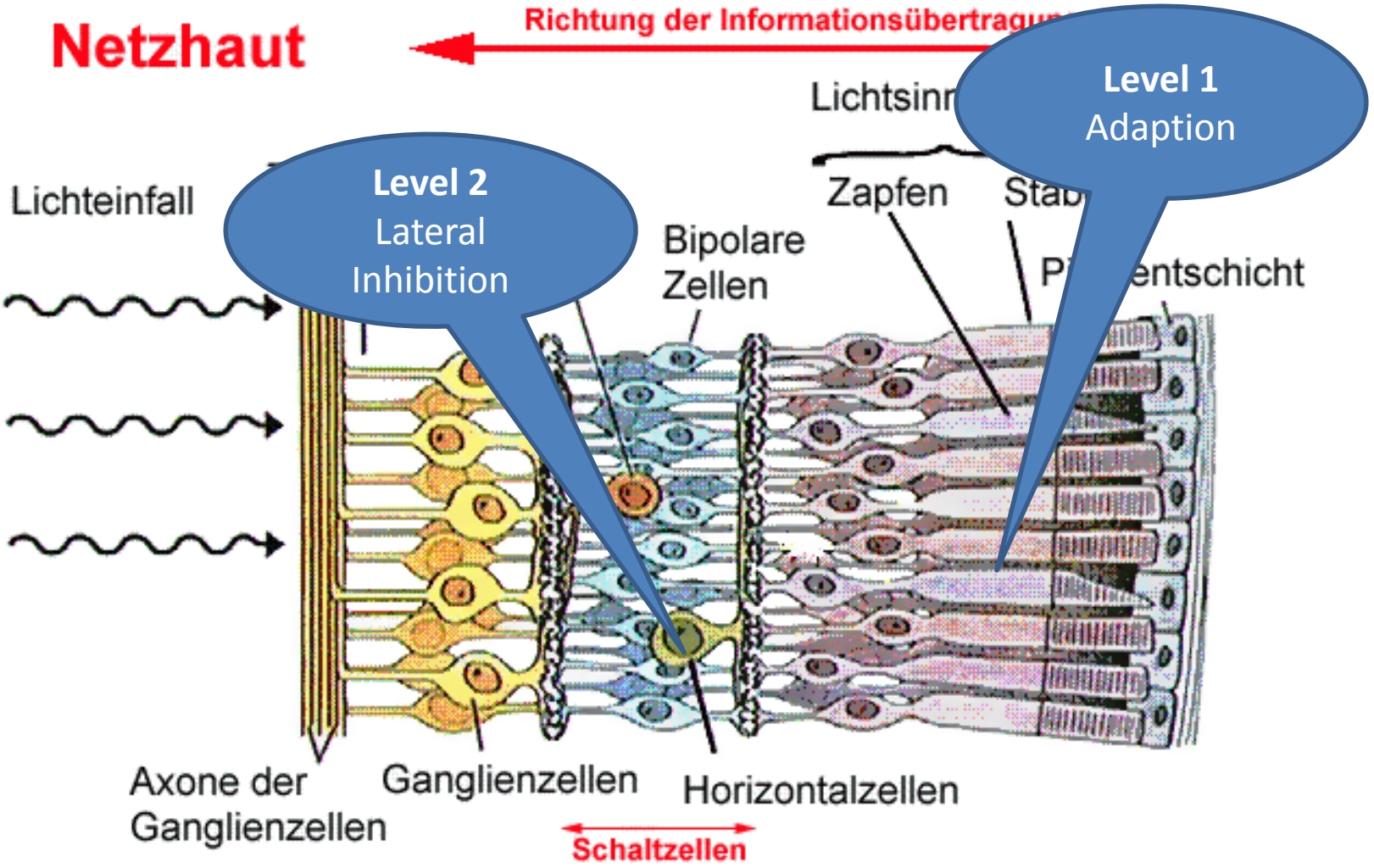
n Depending on the size of the (perceived) object, e.g., n = 0.333 in case of a round light spot or n=0.5 for a point light source

Lightness

- The human eye is able to process color correctly independent from the current Luminance
- The perceived difference of lightness is not bigger than a factor of 2 if a person comes from sunlight to a room (after adaption)
- In general: lightness is constant



Adaption

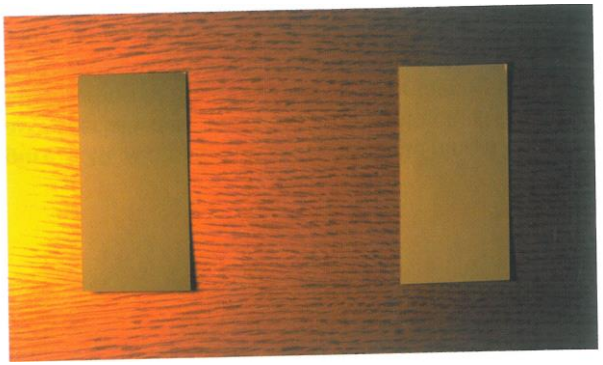

Netzhaut
Richtung der Informationsübertragu
Lichtsinn
Level 1
Adaption
Lichteinfall
Level 2
Lateral
Inhibition
Zapfen
Stab
Bipolare
Zellen
entschicht
Axone der
Ganglienzellen
Ganglienzellen
Horizontalzellen
Schaltzellen

Contrast

- Contrast defines the difference between light and dark parts of an image
- Contrast can be defined as a local (image contrast) or global (gradient) phenomena

$$C = \frac{L_{\max}}{L_{\min}} - 1$$

- L(max/min) specifies the lightest and darkest part in an image



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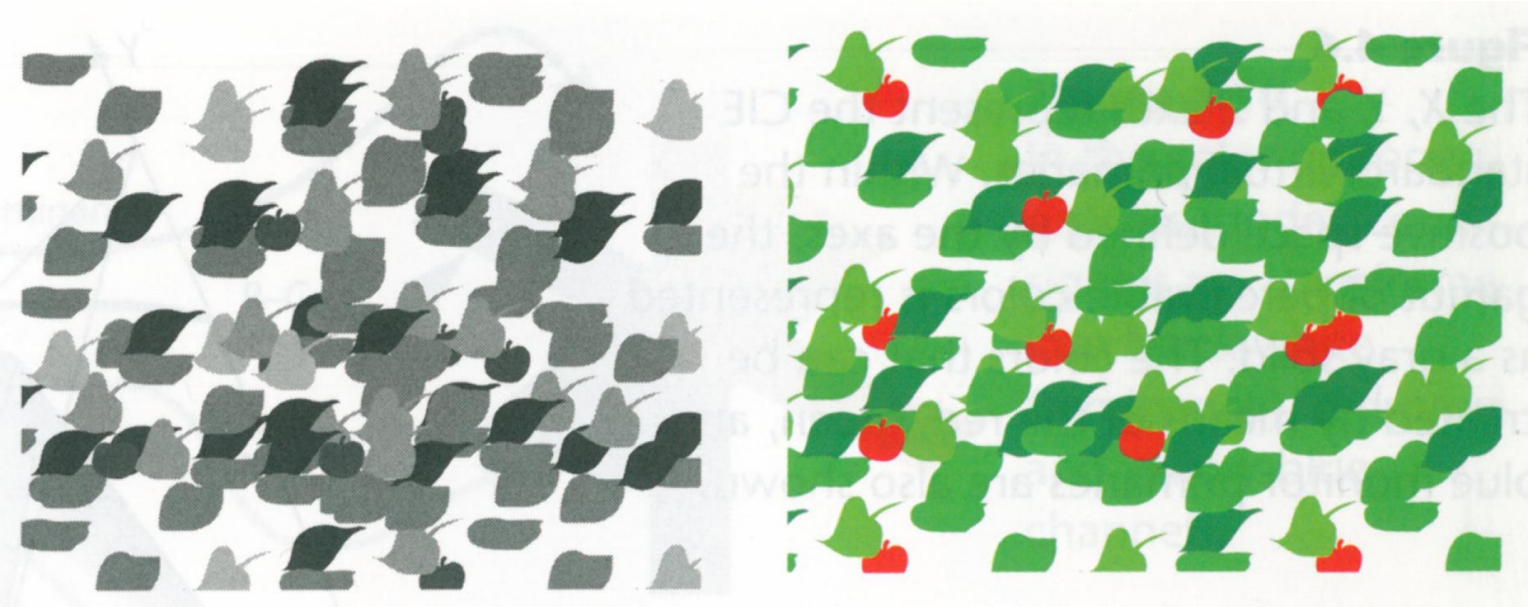
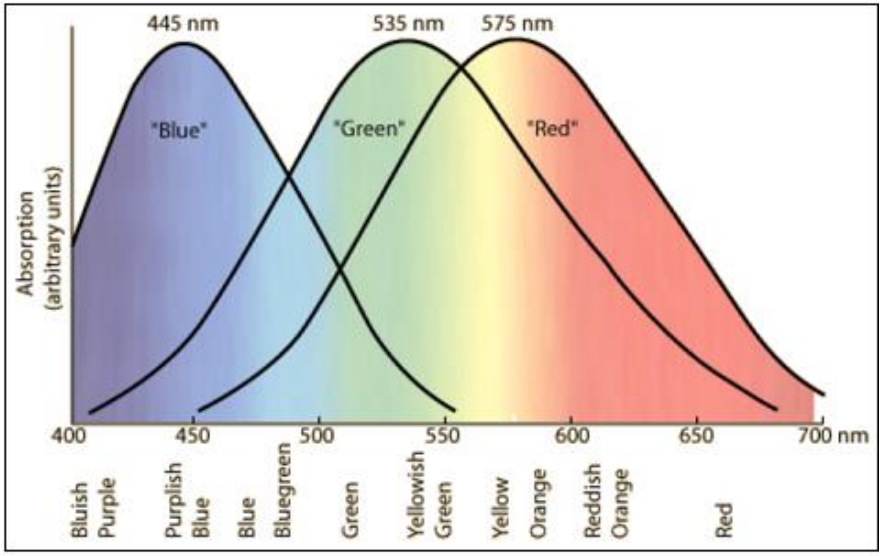
Color

- Color is not a central aspect of visual perception
  - There are many people out there who do not know that they are color blind
- Nevertheless, for the representation of information, color is an important issue
- Color is needed for the differentiation of objects, as far as luminance and brightness are not always enough



Tri-chromatic Theory

- Color perception is only dedicated to the cones
- There are three types of cones, which indicate the tri-chromatic theory
  - Monitor: Red, Green, Blue
  - Art: Red, Blue, Yellow
  - Printer: Cyan, Magenta, Yellow



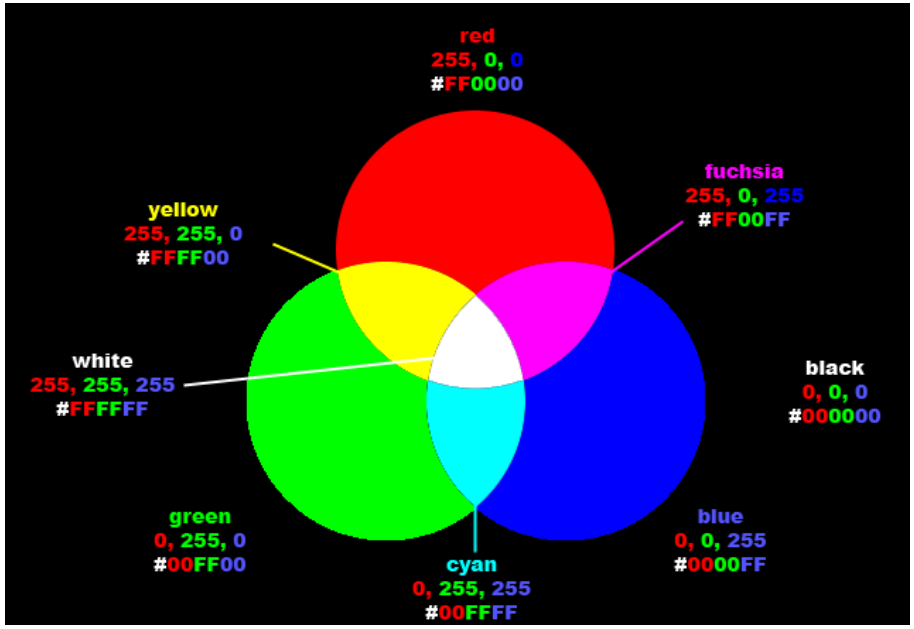
http://www.jands.com.au/__data/assets/image/0013/27130/cones_web.jpg

- The goal of a color system should not be to represent the correct combination of wave lengths but the right amount of light combined from the three parts

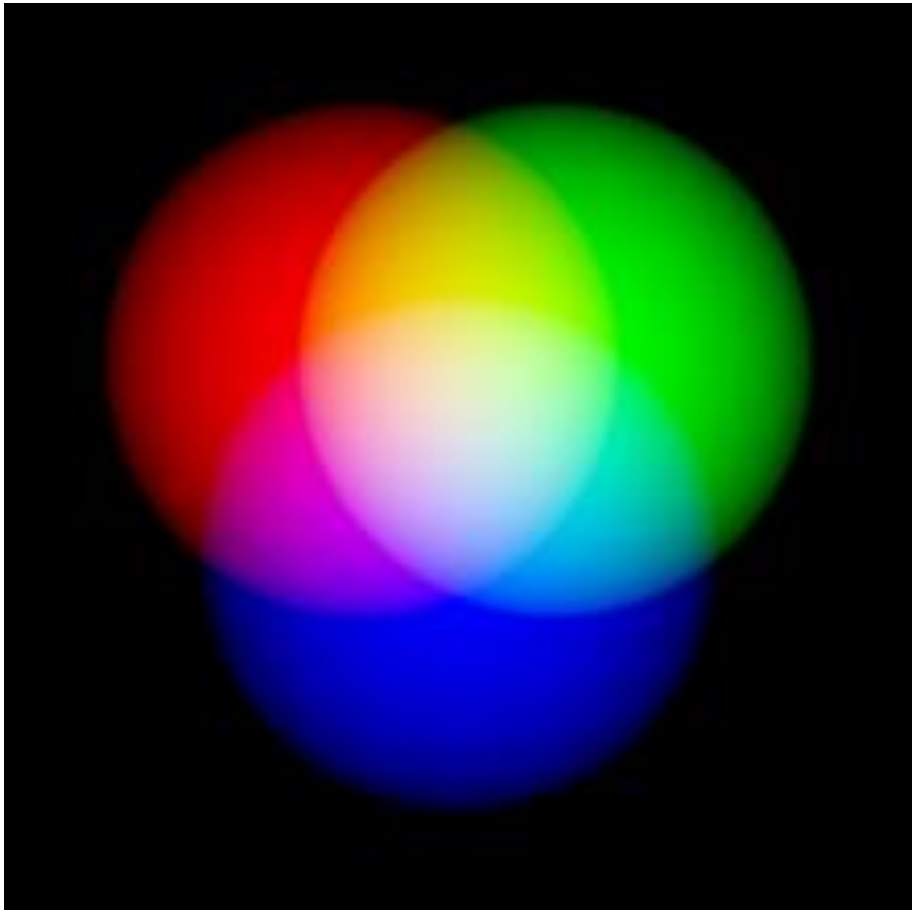
- This combination directly depends on the sensitivity of the receptors

$$C \equiv rR + gG + bB$$

Color Metric



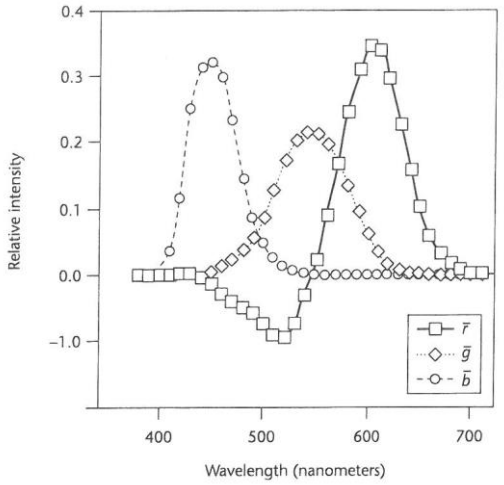
http://www.webmaster-crashkurs.de/bilder/farbmodell-additive-farbmischung.png

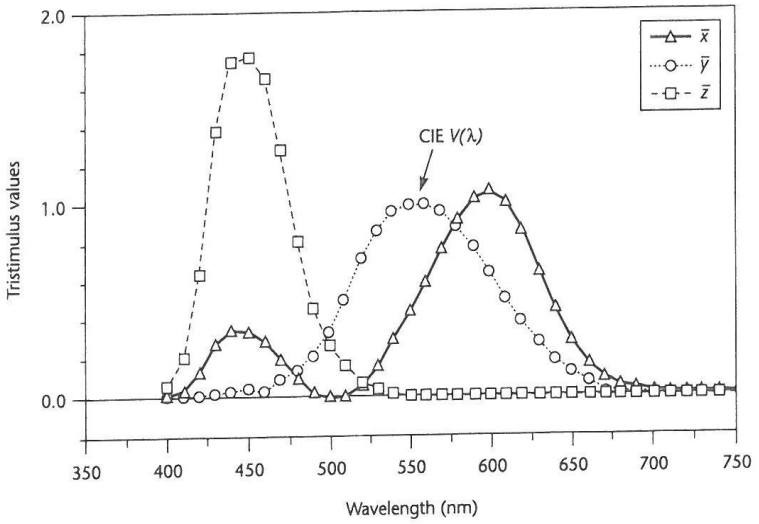


http://upload.wikimedia.org/wikipedia/commons/thumb/3/3b/Additive_RGB_Circles-48bpp.png/220px-Additive_RGB_Circles-48bpp.png

CIE Color System / Standard

- This model is based on a reference pattern of human visual perception
- The color system thereby represents the color perception of one hypothetic (reference) person
- The CIE color model is based on three fictive base-colors, the so called tri-stimuli **X, Y, Z**
- To create this reference model, various persons were confronted with the combination of three light sources (700, 546, and 436 nm), which has been transformed afterwards





CIE XYZ color model

- The transformation has been made along the following requirements:
  - All tri-stimuli (TS) are positive for all colors. This is the reason why the TS do not have a correct physical interpretation.
  - X and Z do not have any luminance information. Only Y specifies luminance in the model

$$X = K_m \int_\lambda E(\lambda)\overline{x_\lambda} d\lambda$$

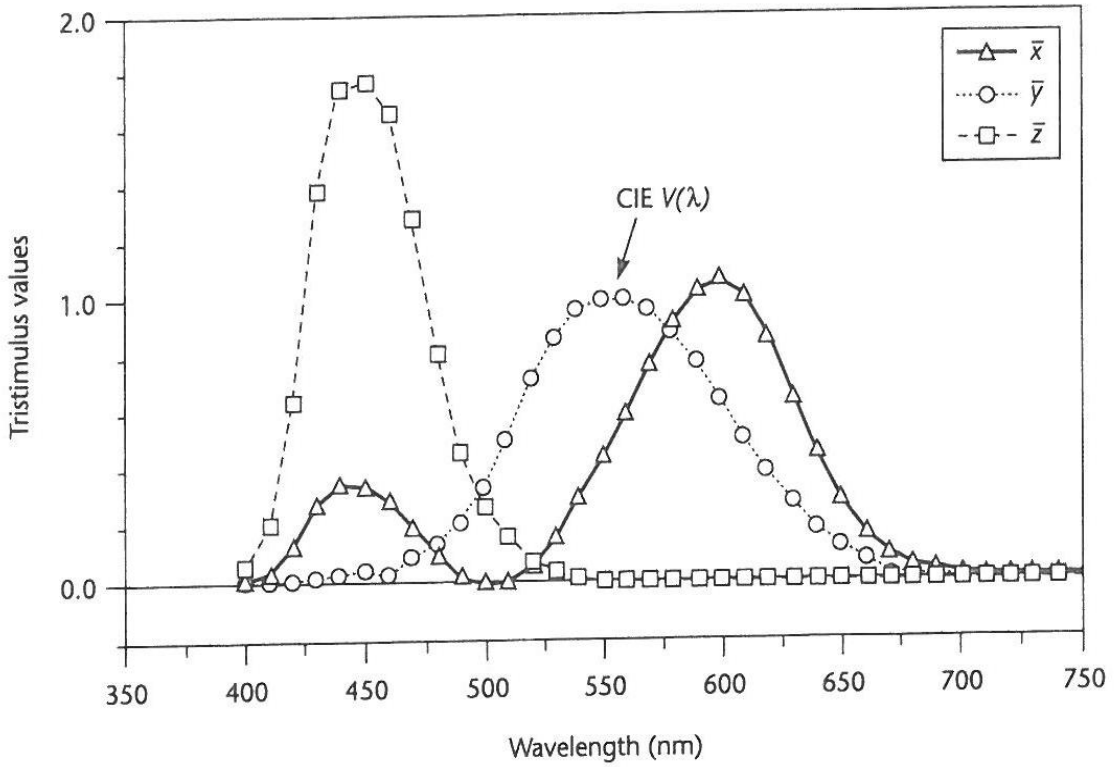
$$Y = K_m \int_\lambda E(\lambda)\overline{y_\lambda} d\lambda$$

$$Z = K_m \int_\lambda E(\lambda)\overline{z_\lambda} d\lambda$$

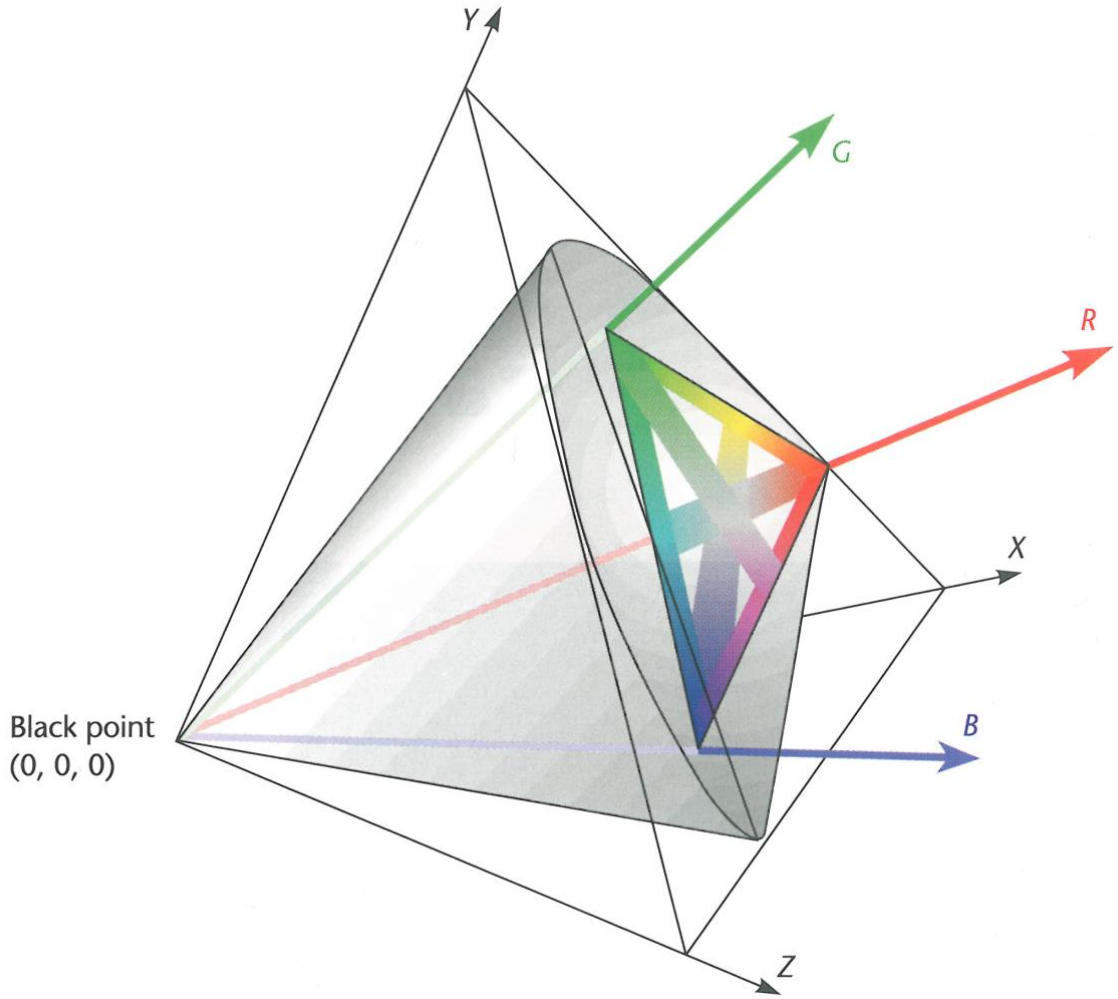
$$K_m = 680 \frac{lm}{W}$$

$E(\lambda)$ Emission strength

$$[E(\lambda)] = \frac{W}{m^2}$$



CIE XYZ color model



CIE XYZ color model

- To simplify the model, chromatic coordinates have been specified to split up the XYZ model into one luminance and 2 chromatic channels

$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z)$$
$$z = Z/(X+Y+Z)$$

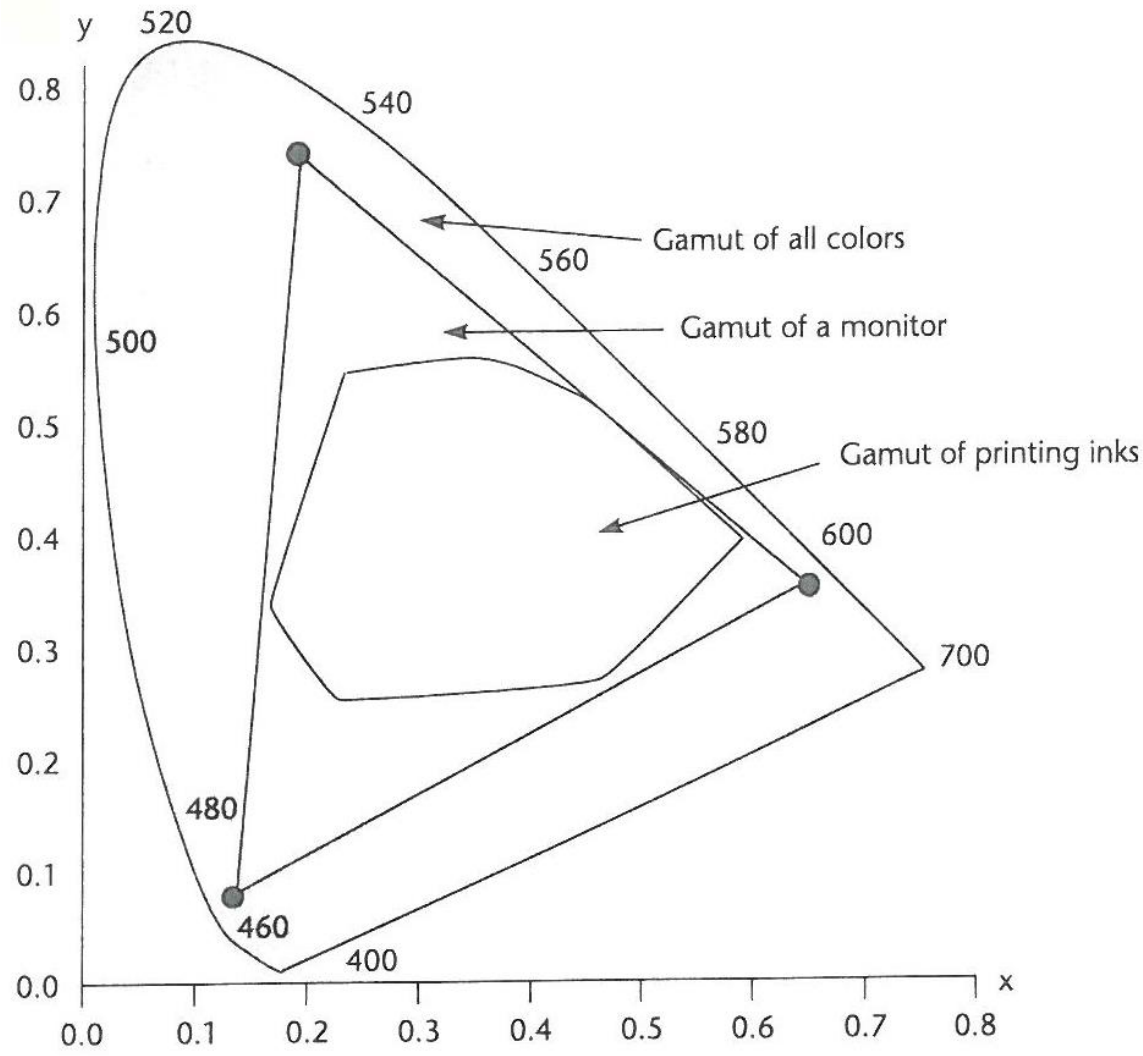
- A color is defined as: $C = (x, y, Y)$

- Because $x + y + z = 1$, it is enough to encounter only x and y, where Y is the luminance
- Reversion of this transformation can then be defined as:

$$X = Y\frac{x}{y}$$
$$Y = Y$$
$$Z = (1-x-y)\frac{Y}{y}$$

Chromatic Diagram

- Every mixture of two colors, which are represented as two points, is lying on the line between these points
- Any three colors specify a Gamut of these colors
- The „violet“ boundary represents the chromatic values of the visible spectrum as straight line
- The distance in the diagram does NOT specify the distance in the perception



CIElab and CIEluv

- The last point is solved by the color models called CIElab and CIEluv

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

$$u^* = 13L^*(u' - u'_n)$$

$$v^* = 13L^*(v' - v'_n)$$

with

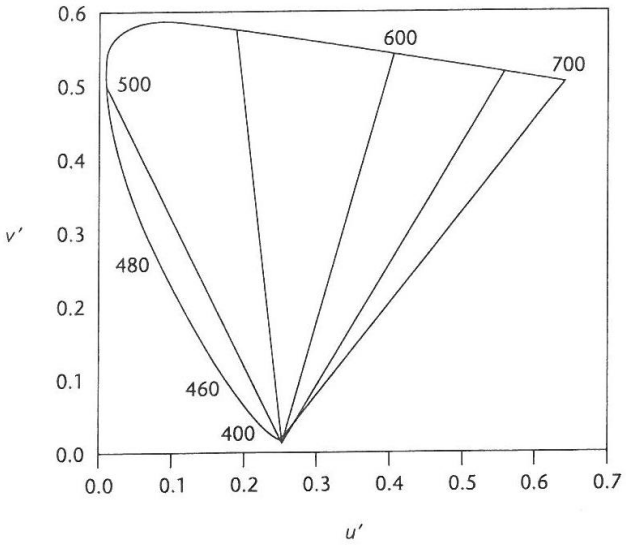
$$u' = \frac{4X}{X + 15Y + 3Z} \qquad u'_n = \frac{4X_n}{X_n + 15Y_n + 3Z_n}$$

$$v' = \frac{9Y}{X + 15Y + 3Z} \qquad v'_n = \frac{9Y_n}{X_n + 15Y_n + 3Z_n}$$

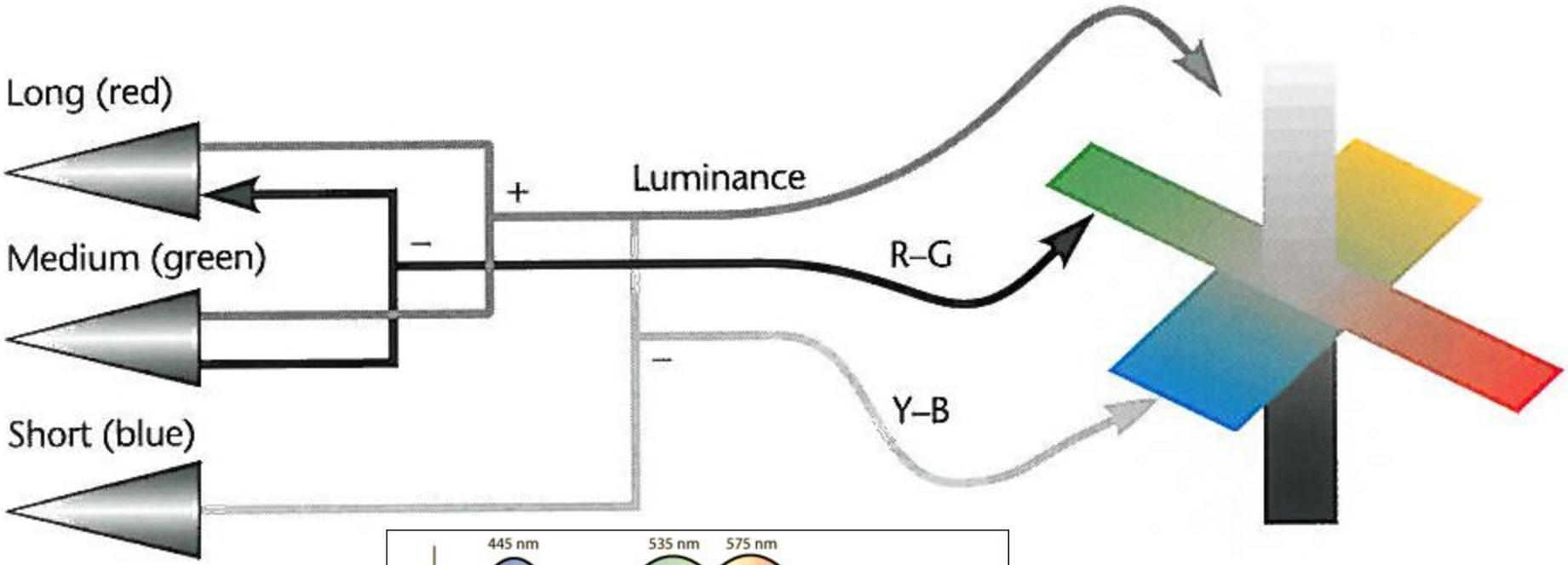
(X_n, Y_n, Z_n) Is the reference white

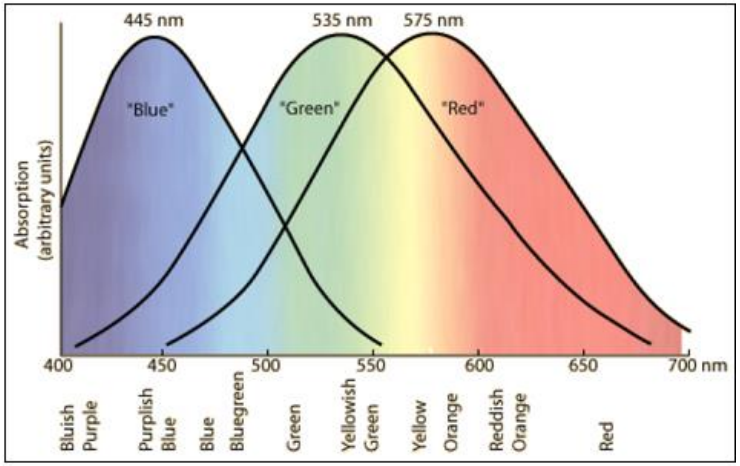
The distance between two colors can be calculated as follows:

$$\Delta E^*_{uv} = \sqrt{(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2}$$



Opponent Process Theory





http://www.jands.com.au/__data/assets/image/0013/27130/cones_web.jpg

1. Spatial Sensitivity:

The efficiency of the chromatic channels is only one third of that of the luminance channel concerning details

1. Spatial Sensitivity:

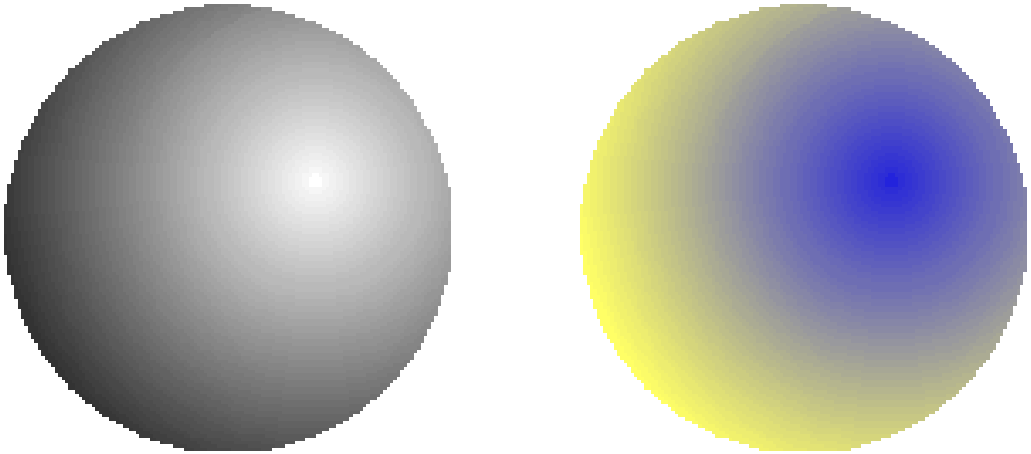
The efficiency of the chromatic channels is only one third of that of the luminance channel concerning details

Characteristics of Color

2. Stereoscopy is close to being exclusively based on the **luminance** channel

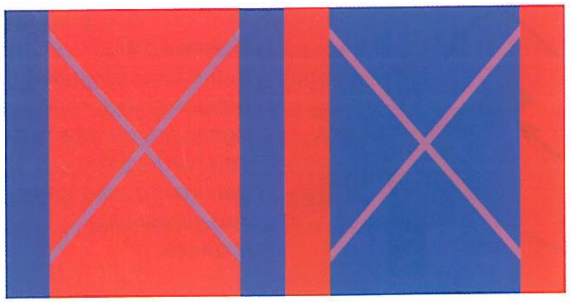
3. Perception of movement is also mainly based on **luminance**

4. The form of an object is mainly based on **luminance gradients** not on chromatic gradients



Why using color?

- Color is **NOT** able to…
  - …represent the form or alignments of objects
  - …estimate distances
  - …remember objects, or
  - …recognize small elements in a certain distance.
- Color **IS** able to..
  - …represent attributes of an object (not its characteristics)
- Relevant are color contrast and saturation

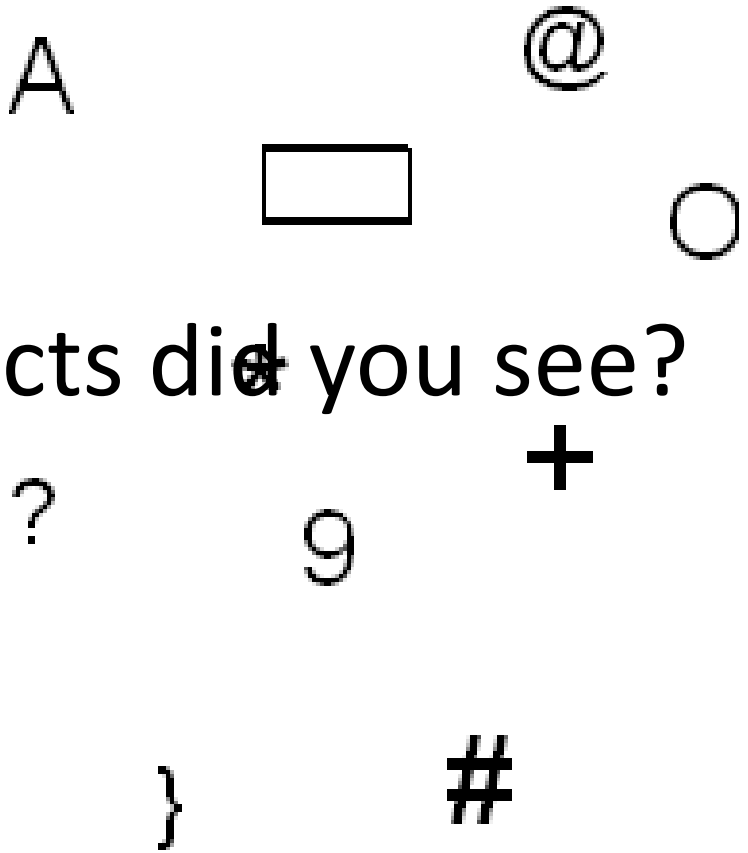


- Brown is a special color, because it is a dark yellow but is not recognized as such

Overview

- Introduction
- Sensory vs. Arbitrary Symbols
- The Human Eye
- Luminance, Contrast, Color
- **Gestalt Psychology**

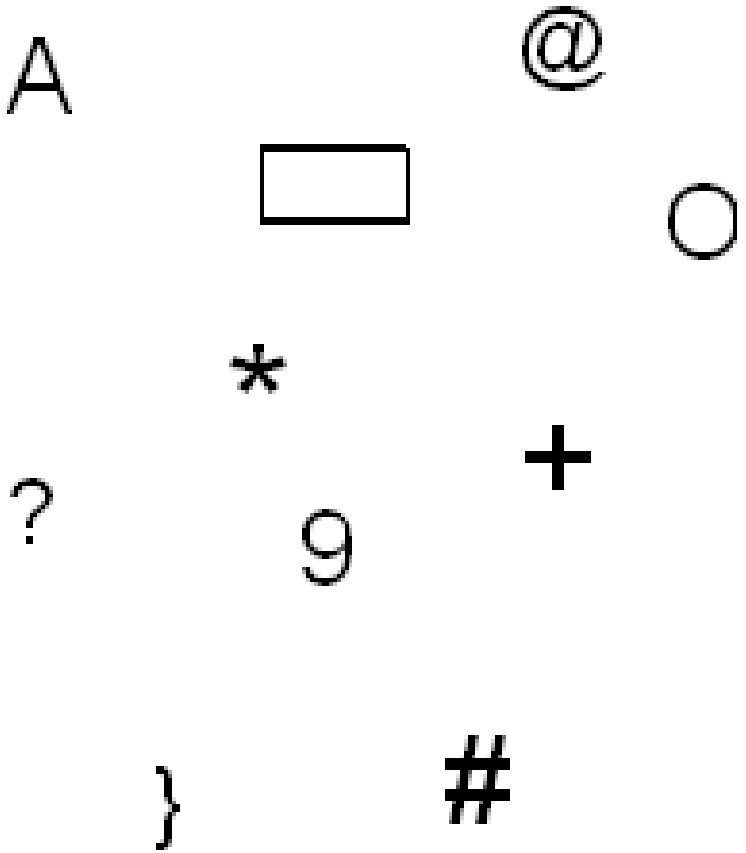
Iconic Buffer



Which objects did you see?

Make a list!

Iconic Buffer



Iconic Buffer

- The iconic buffer is able to store up to 7 objects, until short term memory is exhausted (3-7 chunks)

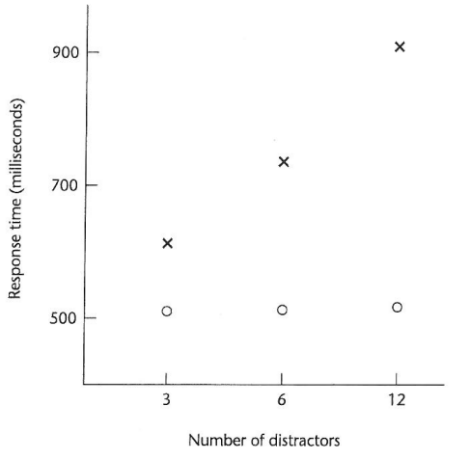
- The limitations of the iconic buffer are
  - Decay of the buffer
  - Speed for reading from the buffer
  - Limited number of storable items (max 7)

Pre-attentive Processing

- Pre-attentive processing describe the cognitive process of perceiving objects before they are intentional realized

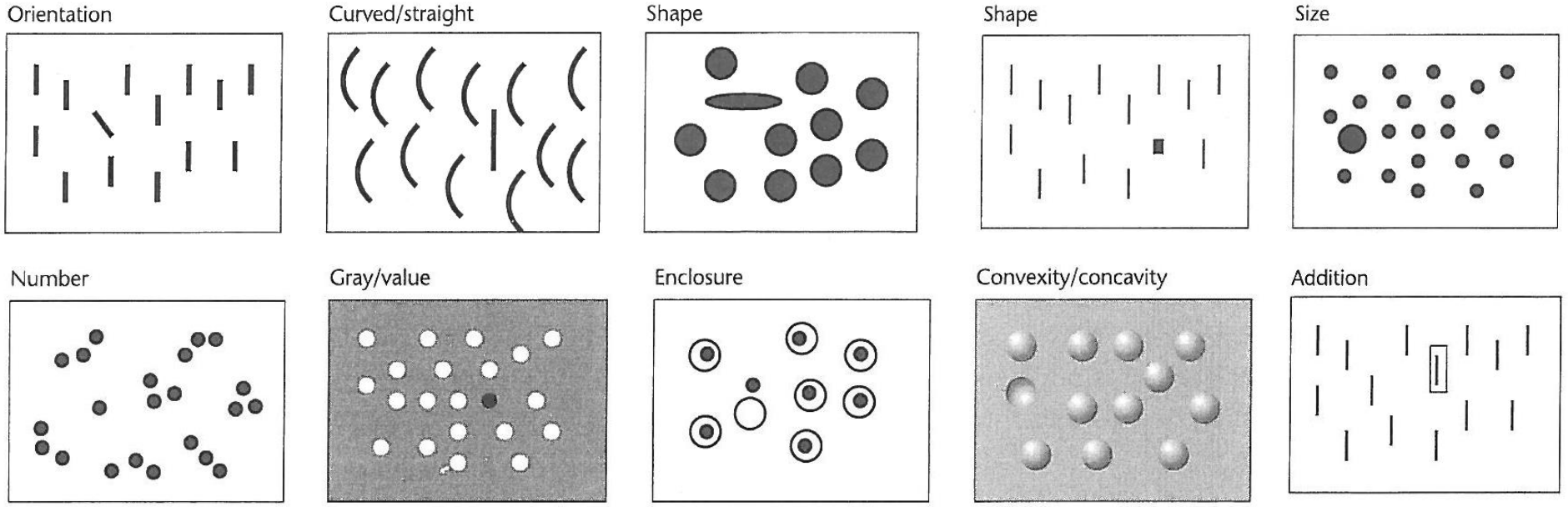
1 4 1 5 9 2 6 5 **3** 5 8 9 7 9 **3** 2 **3** 8 4 6 2 6 4 **3** **3** 8
3 2 7 9 5 0 2 8 8 4 1 9 7 1 6 9 **3** 9 9 **3** 7 5 1 0 5 8
2 0 9 7 4 9 4 4 5 9 2 **3** 0 7 8 1 6 4 0 6 2 8 6 2 0 8
9 9 8 6 2 8 0 **3** 4 8 2 5 **3** 4 2 1 1 7 0 6 7 9 8 2 1 4
8 0 8 6 5 1 **3** 2 8 2 **3** 0 6 6 4 7 0 9 **3** 8 4 4 6 0 9 5
5 0 5 8 2 2 3 1 7 2 5 **3** 5 9 4 0 8 1 2 8 4 8 1 1 1 7
4 5 0 2 8 4 1 0 2 7 0 1 9 **3** 8 5 2 1 1 0 5 5 5 9 6 4

- Objects are perceived pre-attentive, if the time to perceive these objects is constant with an increasing number of distractors
- *Rule of thumb:* Everything what is processed faster than 10ms per item is pre-attentive

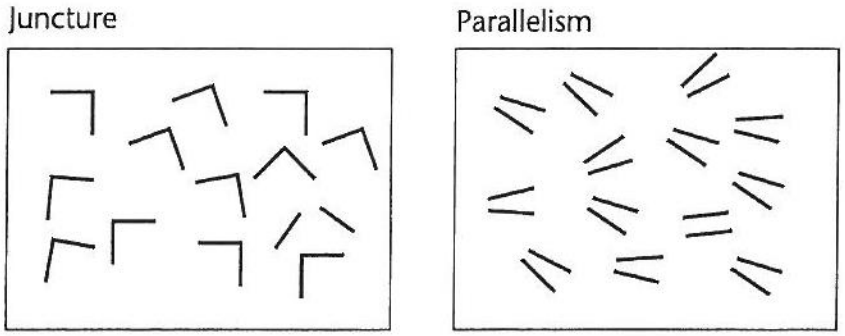


Pre-attentive Processing

Pre-attentive



NOT Pre-attentive



Pre-attentive Processing

Form
- Line orientation
- Line length
- Line width
- Co-linearity of lines
- Size
- Roundness
- Spatial grouping
- Additive markings
- Number

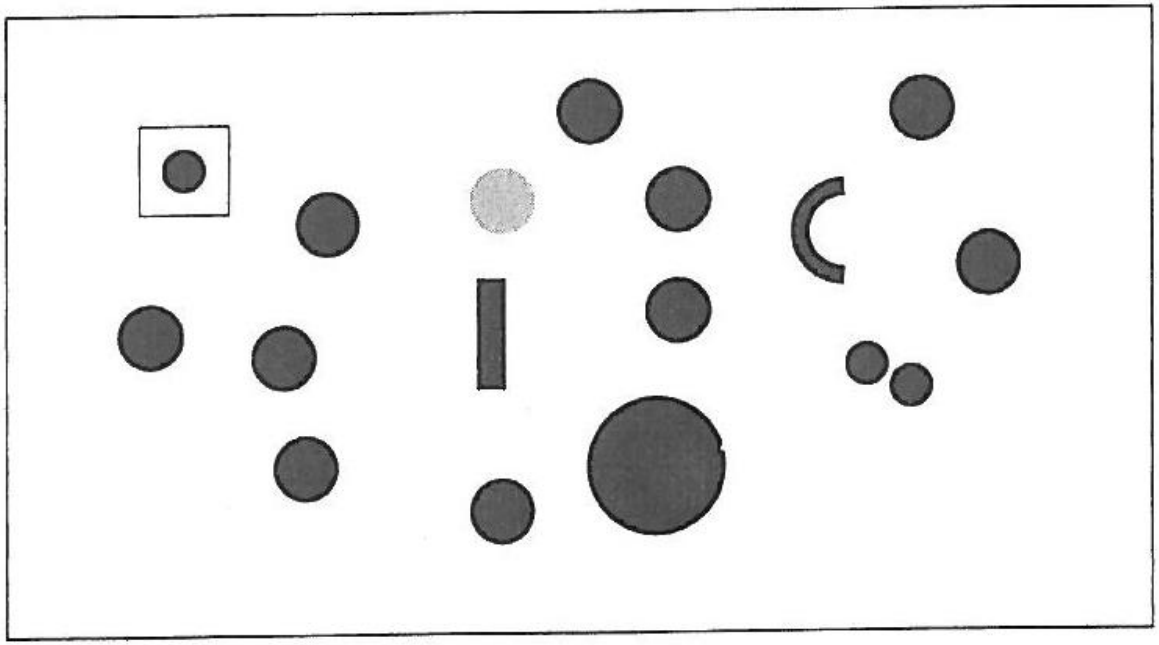
Color
- Color
- Intensity

Spatial Position
- 2D Position
- Stereoscopic depth
- Convex and concave shading

Movement
- Flicker
- Direction

Pre-attentive Processing

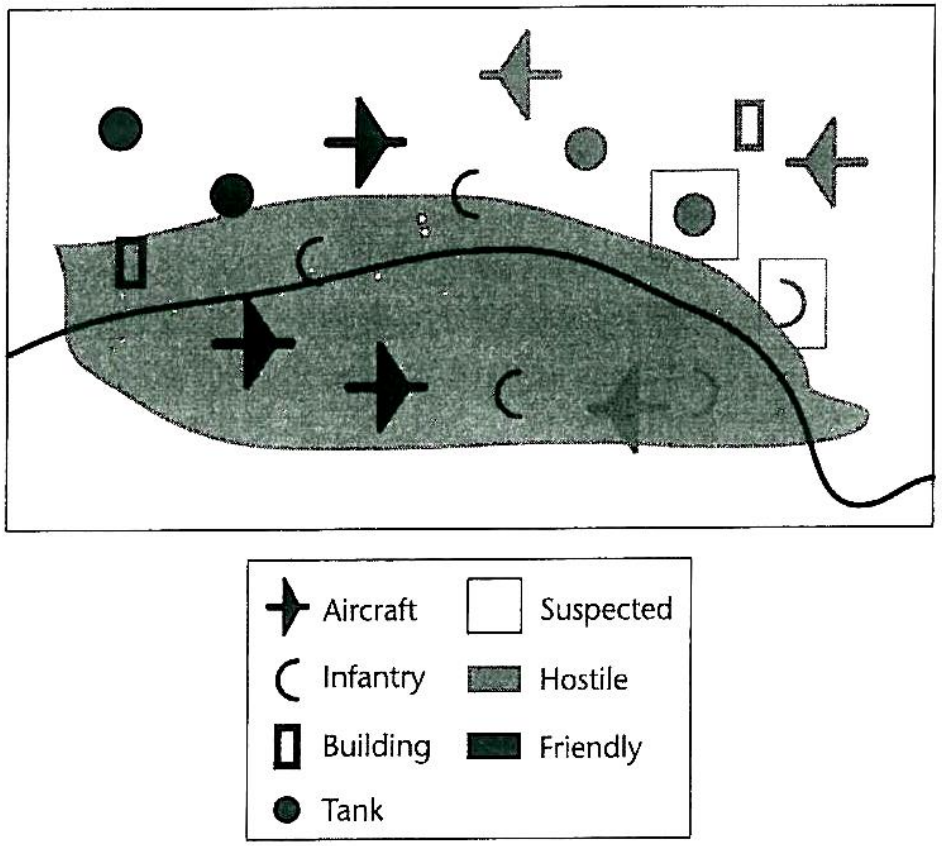
- These concepts can be combined, such as used in geographic maps



Pre-attentive Processing

- Pre-attentive processing should be the basic concept for the creation of symbol sets
- Example: Military maps
  - Aim for planes
  - Aim for tanks
  - Buildings
  - Aim for infantry

  Furthermore:
  - Visibility of enemy and friend
  - Visibility of suspects



Overview

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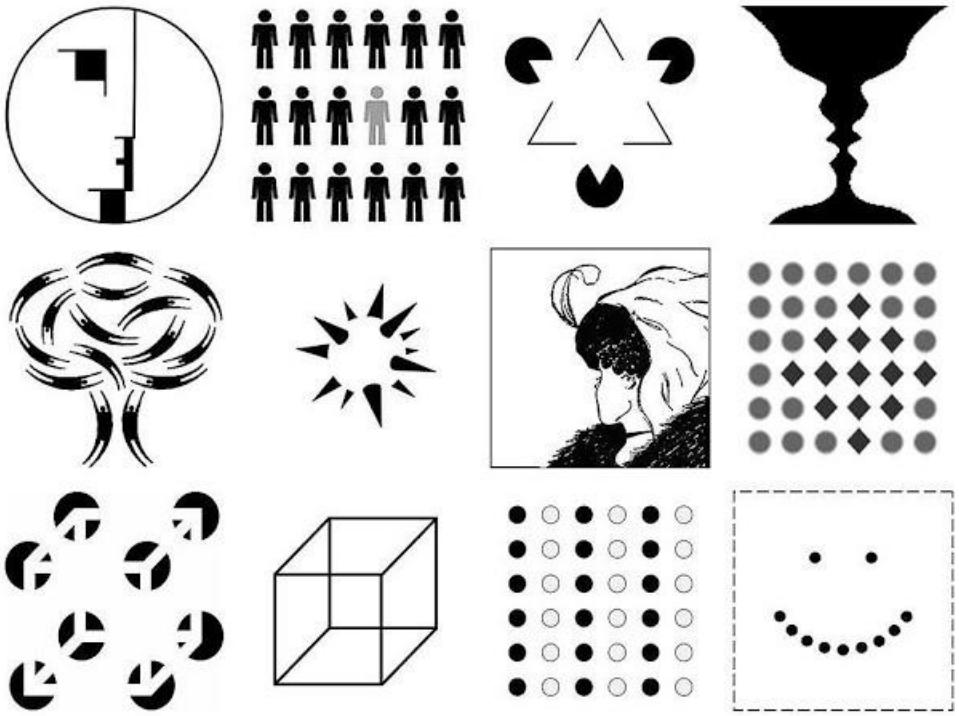
Gestalt Psychology

- Gestalt laws of grouping
  - Law of Proximity
  - Law of Similarity
  - Law of Closure
  - Law of Symmetry
  - Law of Common Fate
  - Law of Continuity



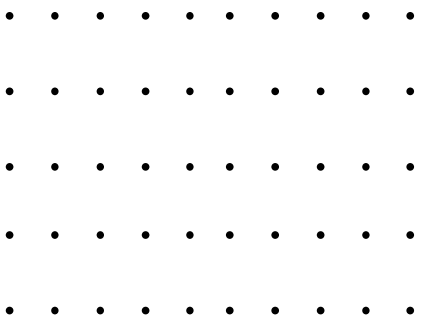
http://en.wikipedia.org/wiki/Gestalt_psychology#mediaviewer/File:Gestalt_Principles_Composition.jpg

Law of Proximity

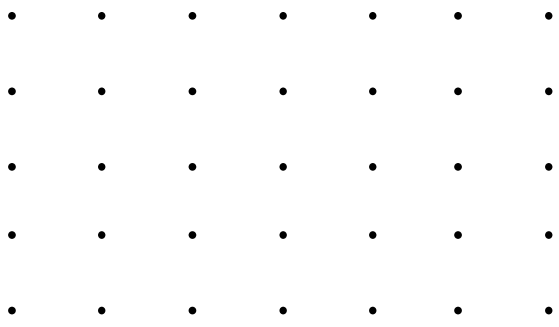
Things that are spatial close together are perceived as belonging together

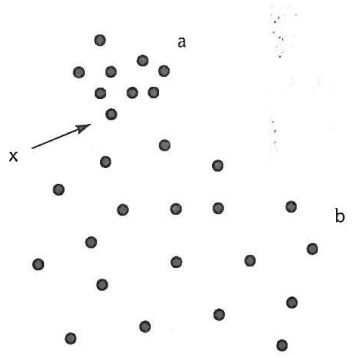
- This law has been identified as the strongest of all Gestalt laws

(a)



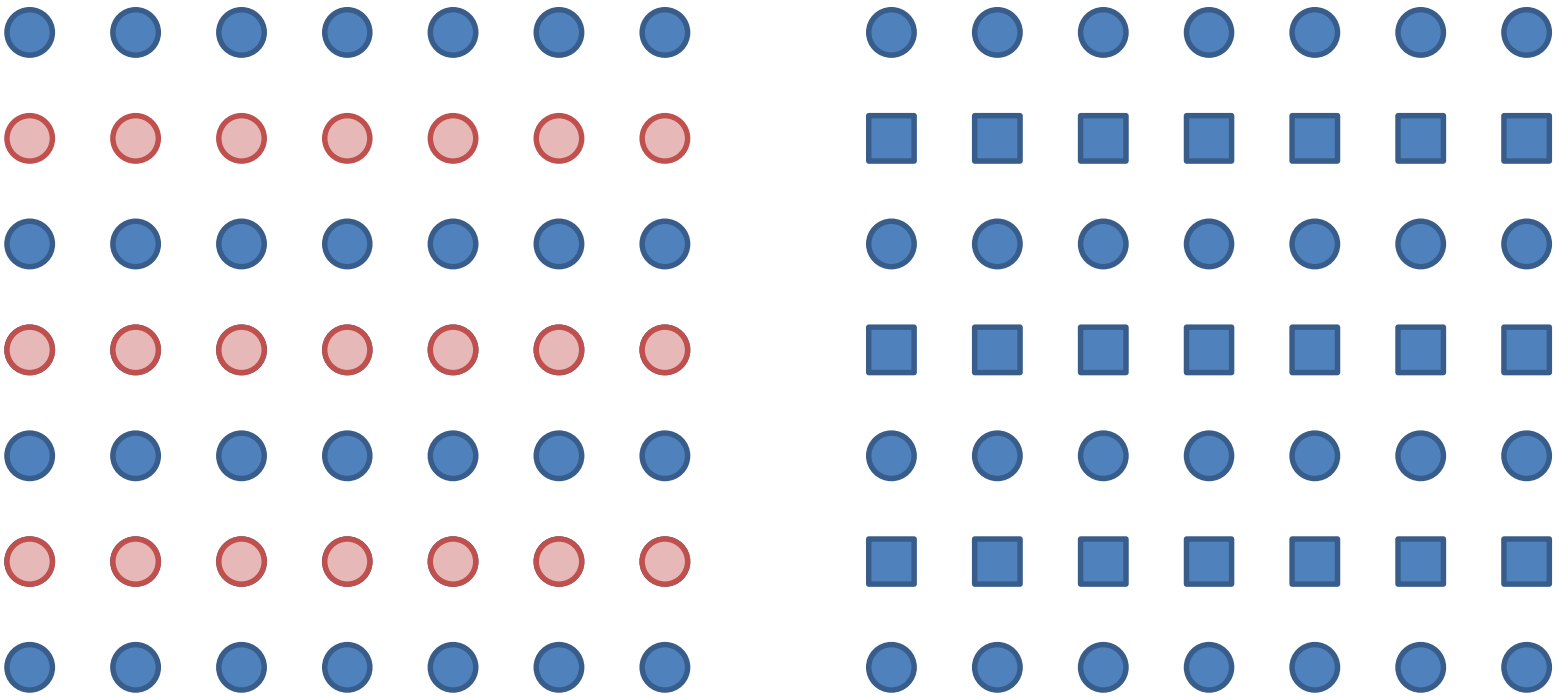
(b)





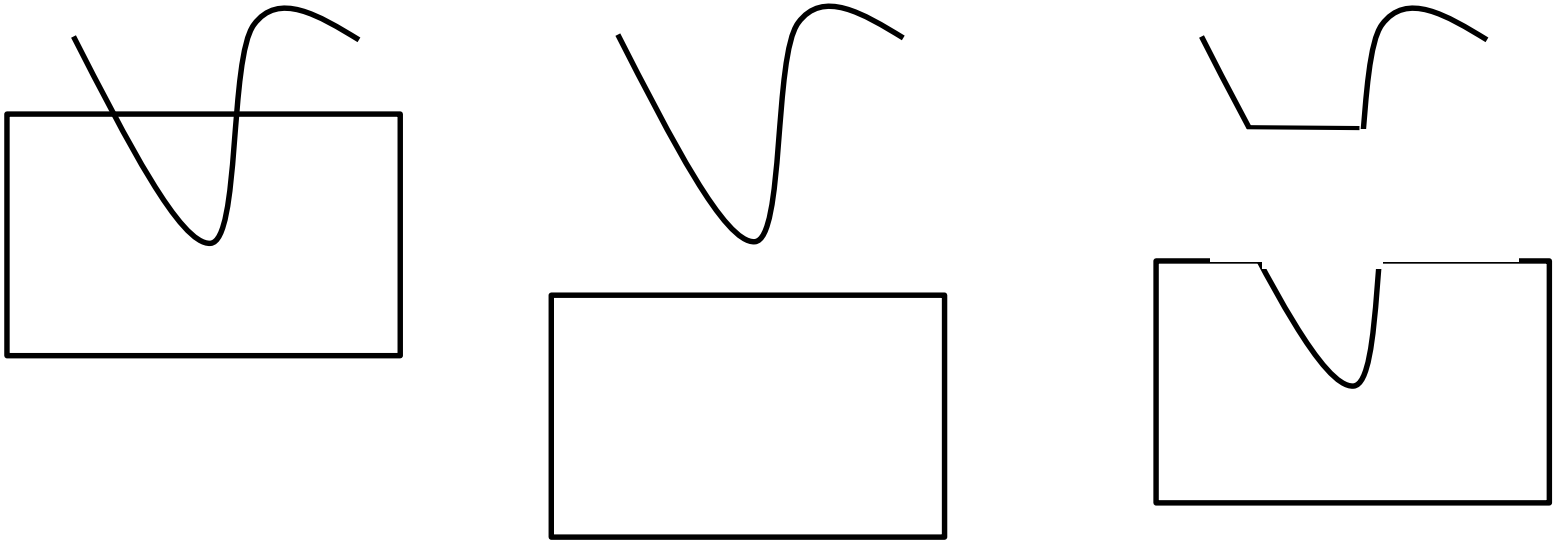
Law of Similarity

Things that are similar in form or color are perceived as belonging together



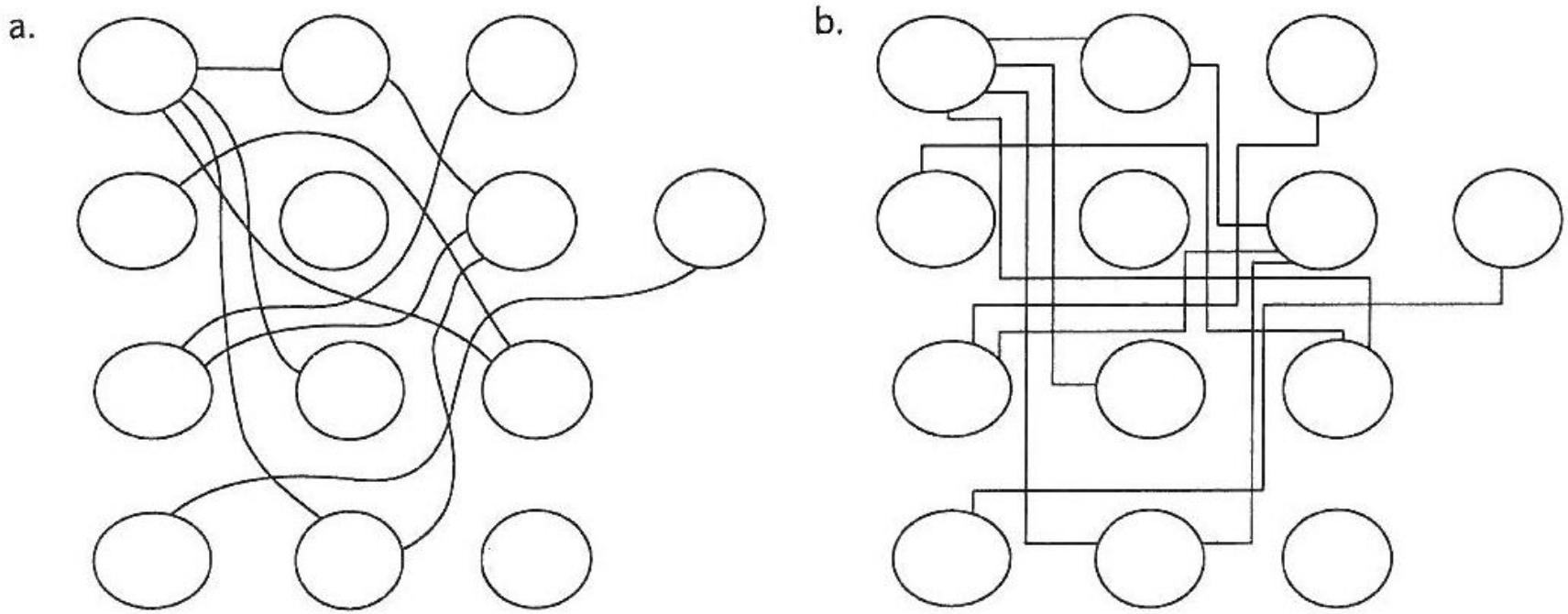
Law of Closure

The human cognition prefers to perceive continuous forms and gradients instead of abrupt break offs



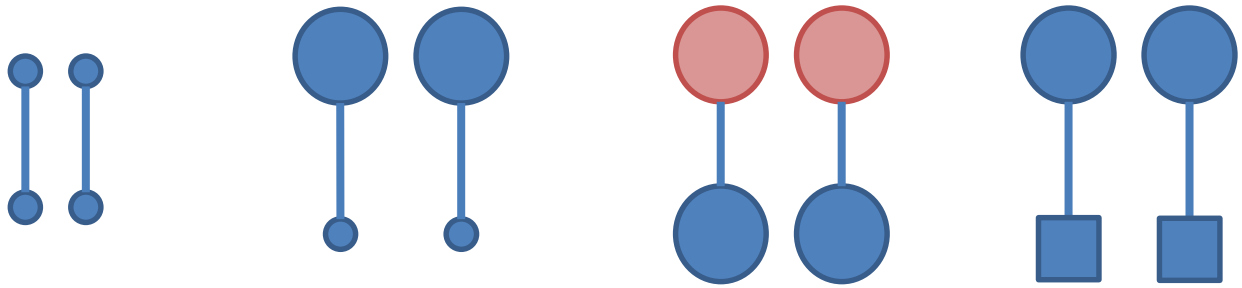
Law of Continuity

The human cognition prefers to follows continuous lines



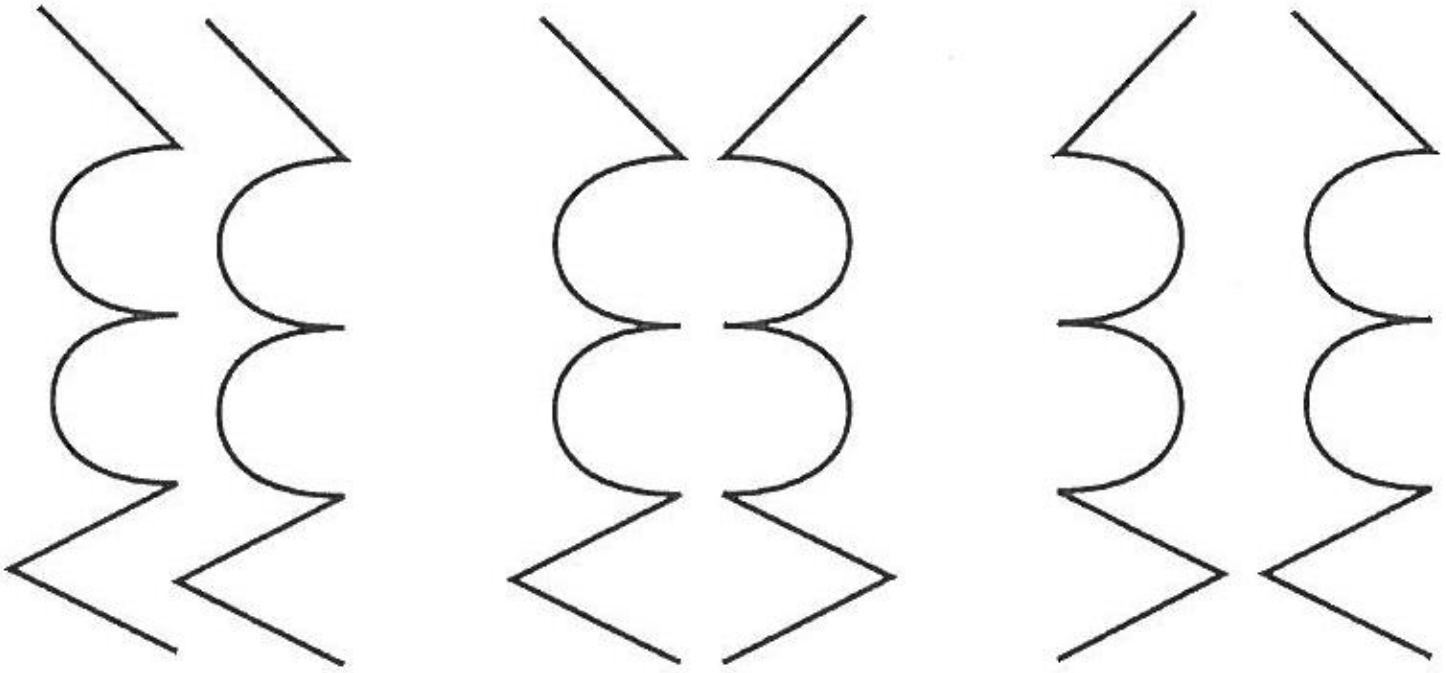
Law of Continuity

- Palmer and Rock (1994) posed that connectivity is stronger than proximity, color, size, and form, where continuity assumes connectivity



Law of Symmetry

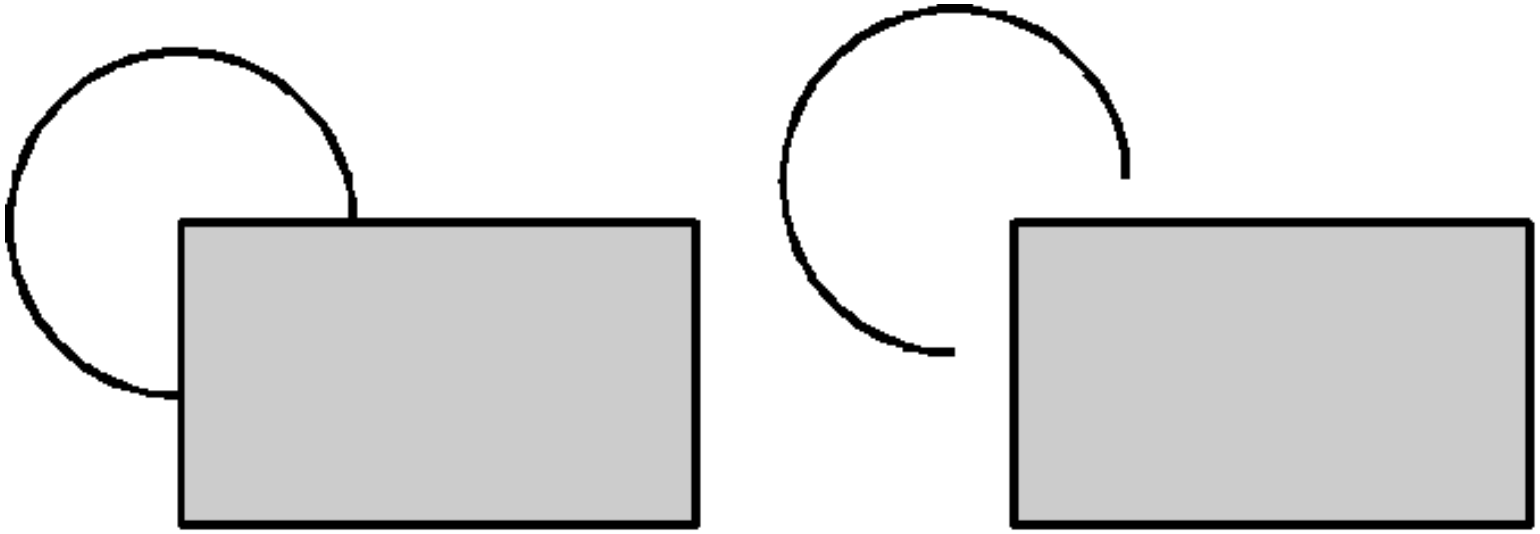
The law of symmetry poses that symmetrical positioned constructions are perceived as one



Law of Closure

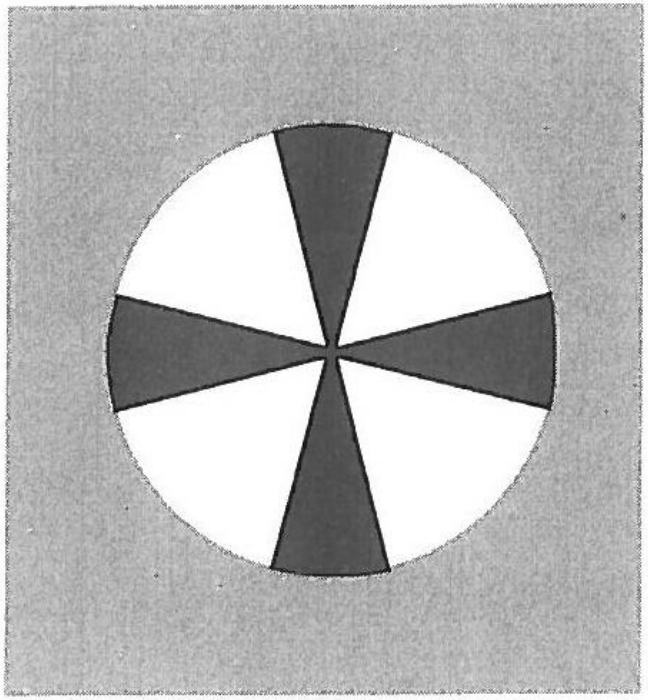
The law of closure poses that closed contours are perceived as object

- Closed contours define inner and outer parts



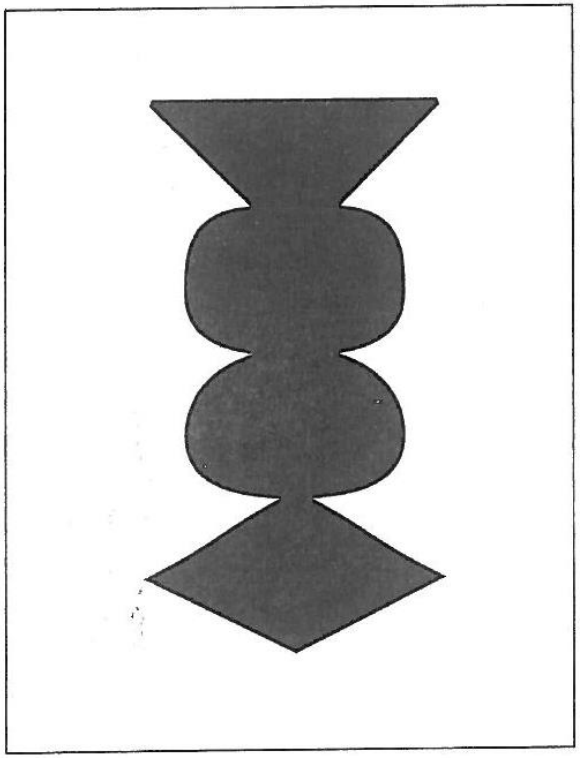
Law of Relative Size

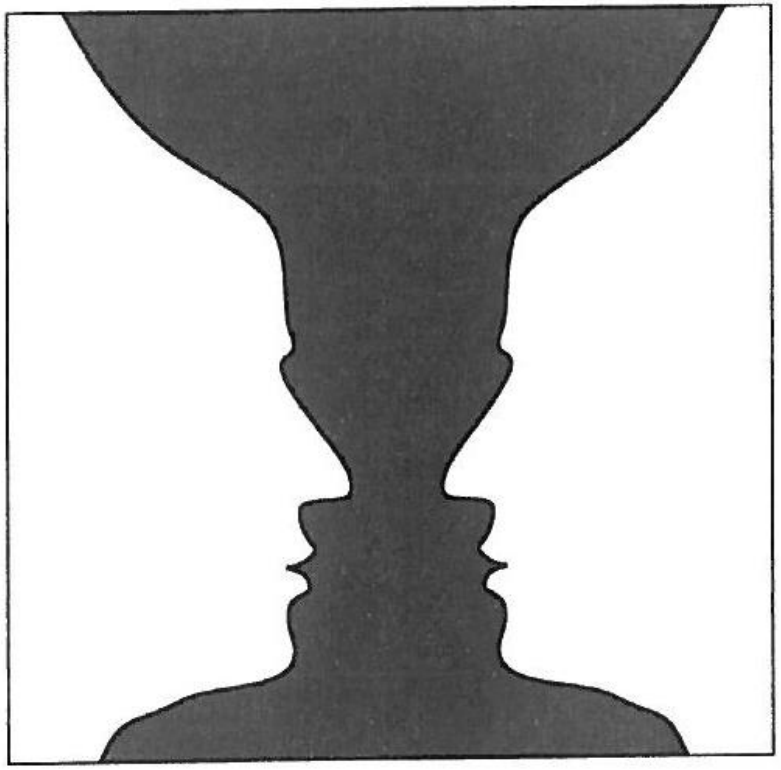
The law of relative size poses that smaller components in a pattern are recognized as object



Law of the Figure-Background Effect

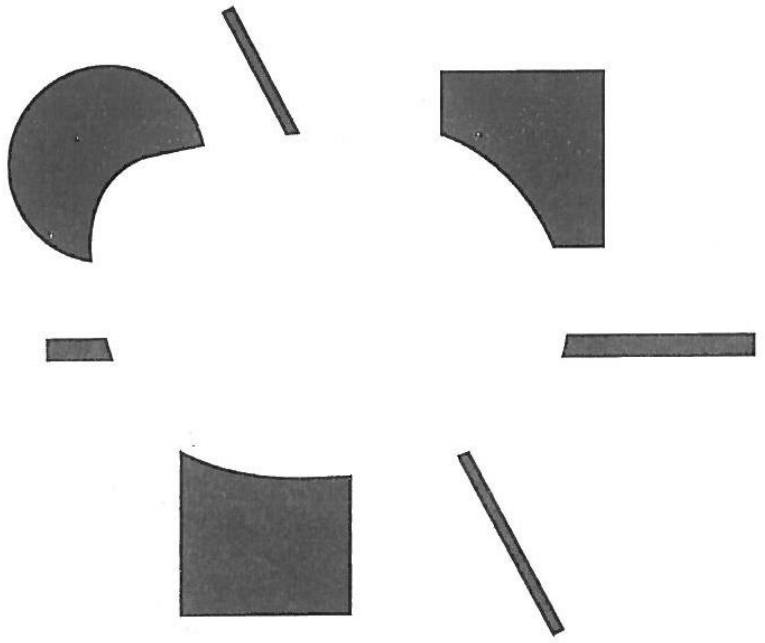
The differentiation of figure and background is one of the basic principles of cognition



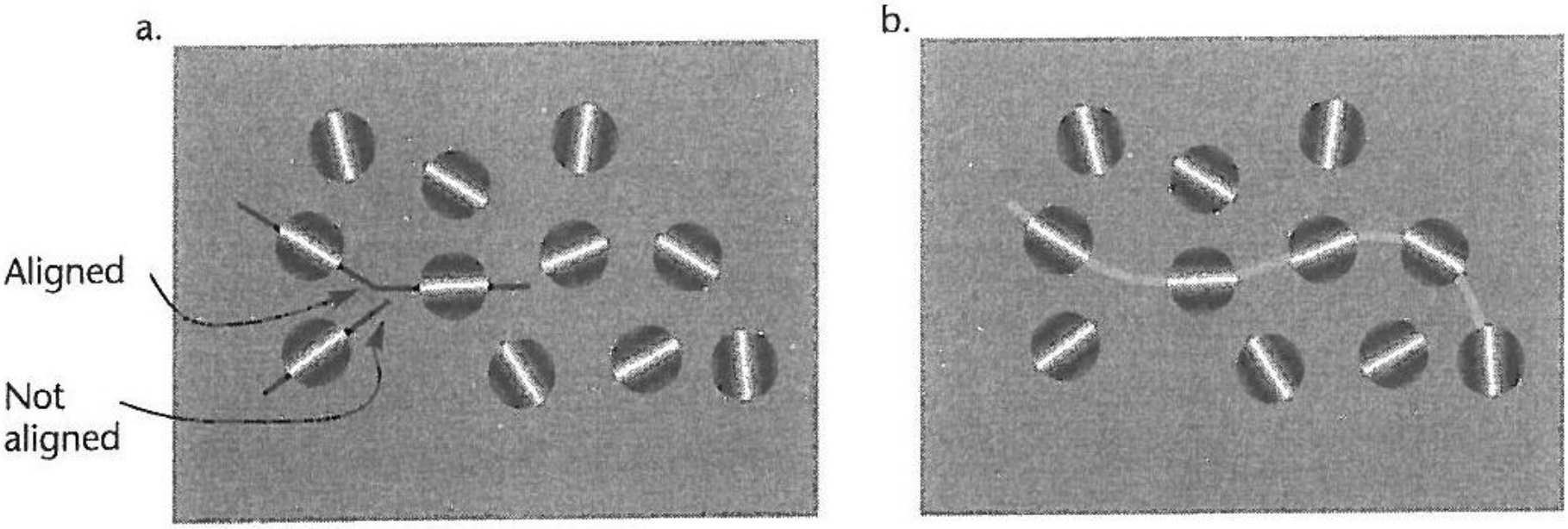


Contours

- A contour is defined as perceived boundary between two regions of a visual image
- A contour can be defined as
  - Line
  - A boundary between two regions of different color
  - Stereoscopic depth
  - Moving patterns
  - Textures
- It is not completely solved, how perception of contours work
- It seems to be a process of neuronal level

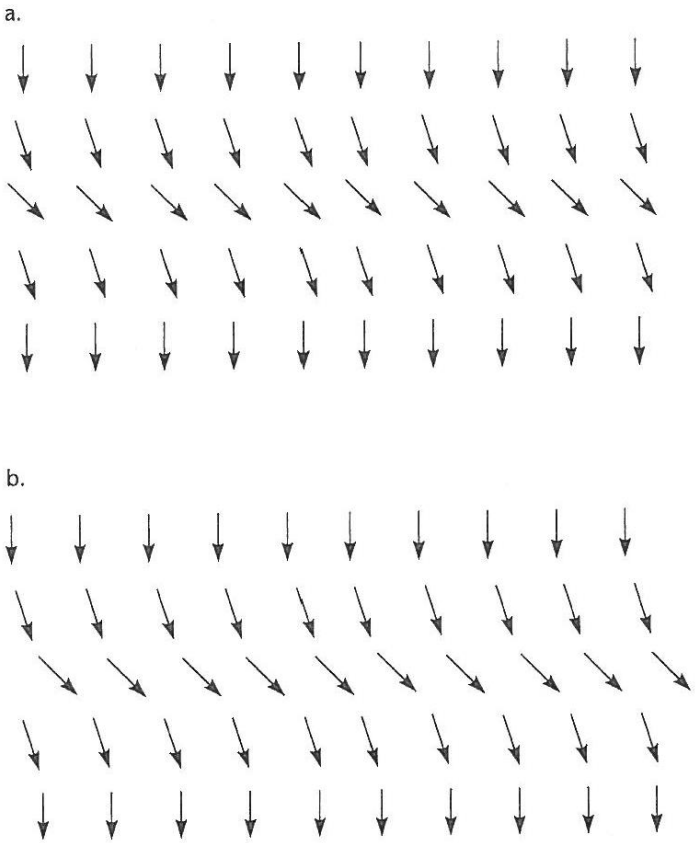


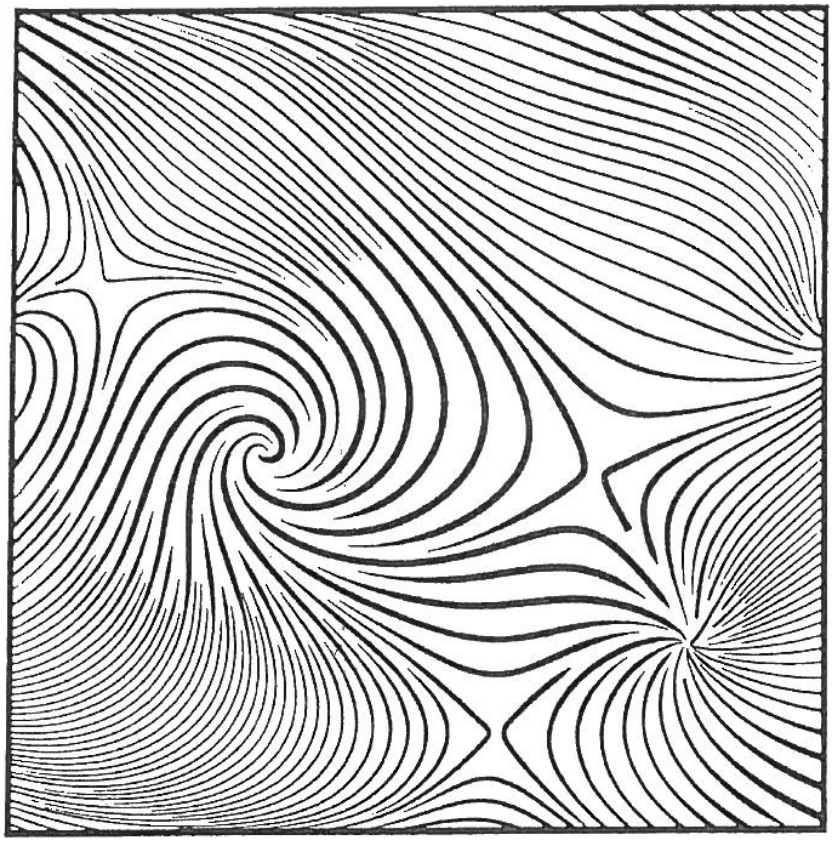
Contours



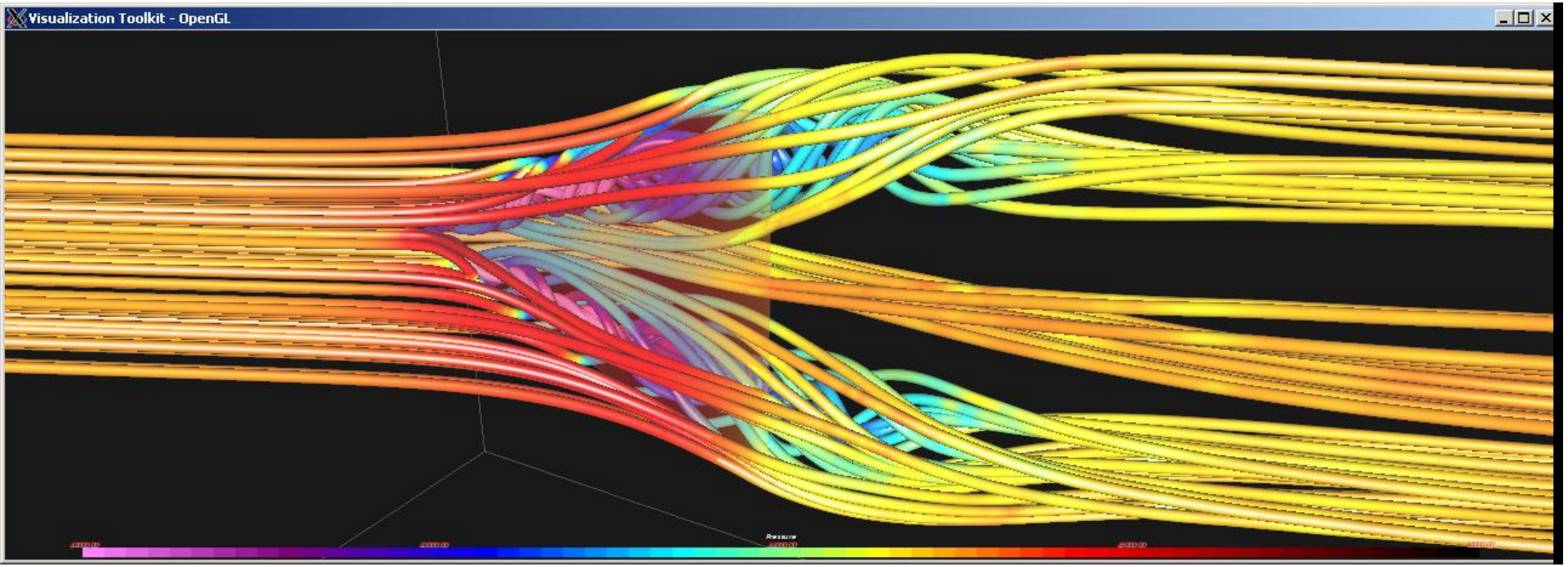
Direction

- Concepts to represent and perceive direction in images
- Continuous lines work better, but do not indicate the direction





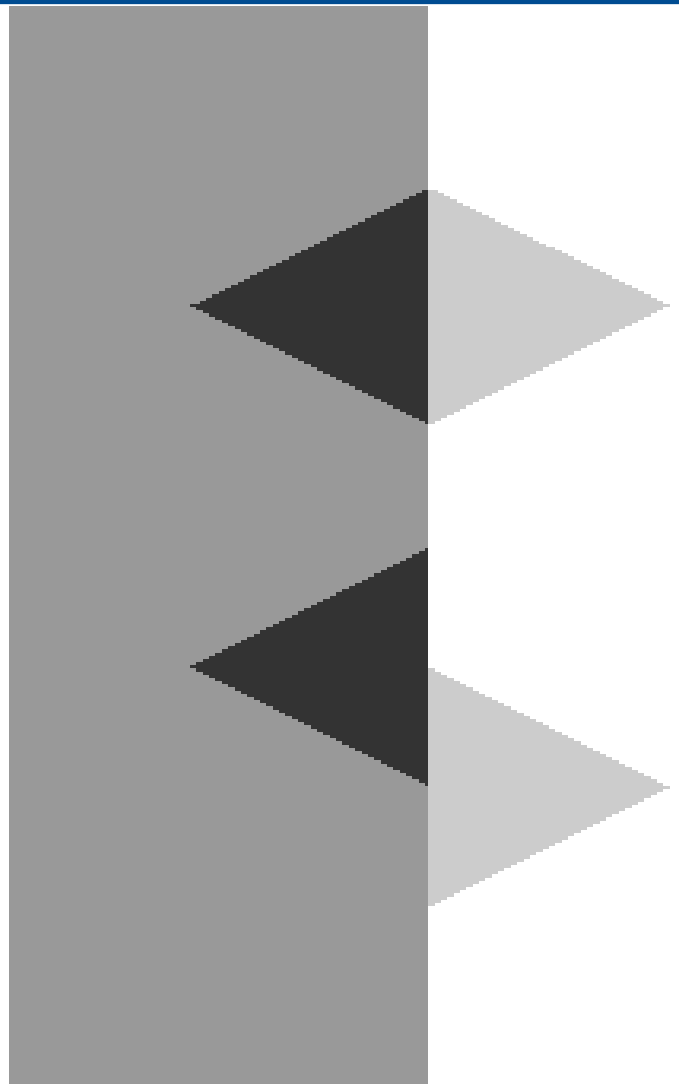
Direction



http://www.eng.utah.edu/~ehan/math6790/project2/images/underneath.png

Transparency

- Representing data and various layers can be helpful but also could cause problems
- The perception of transparency is based on continuity and the right gray shading

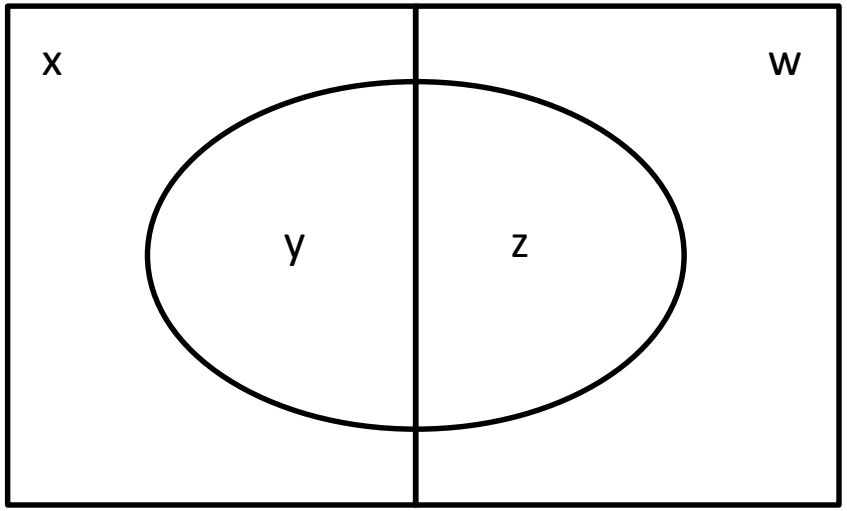


Transparency

- The right choice of gray scale can be defined as follows

$$x < y < z$$
$$y < z < w$$
$$y > z > w$$

Where x, y, z and w are gray values



Transparency

- The combination of patterns can be used for representing transparency
- The concept of perceptional inference should be encountered: Different textures interfere in different ways:
  - Similar color
  - Similar pattern
  - Similar movement
  - Similar frequency
  - …

One Minute Paper

- Used as Feedback from **you** to **me**
- Anonymous
- Take a piece of paper and use for **front** for **positive feedback** and the **back** for **negative feedback**
- Do this at the end of the lecture
- This will be repeated at in January and at the end of the course.